388.4
Z13s

ENGINEERING LIBRARY
UNIVERSITY OF ILLINOIS
URBANA, ILLINOIS 61801

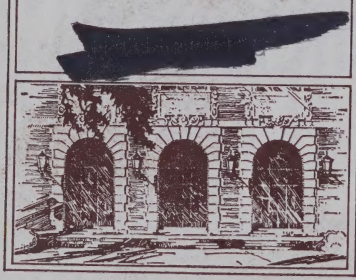
SYNTHESIZING A TRANSPORTATION STUDY BY THE 'IN' PROCEDURE

YACOV ZAHAVI

UNIVERSITY OF TECHNOLOGY
OF DELFT

LIBRARY OF THE
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

388.4
Z13s



SYNTHESIZING A TRANSPORTATION STUDY BY THE 'IN' PROCEDURE

Proefschrift

ter verkrijging van de graad van doctor in de technische wetenschappen aan de Technische Hogeschool Delft, op gezag van de Rector Magnificus ir. H.R. van Nauta Lemke, hoogleraar in de afdeling der Elektrotechniek, voor een commissie aangewezen door het College van Dekanen te verdedigen op woensdag 28 februari 1973
te 16.00 uur

door

Yacov Zahavi

Dipl. Ing.

geboren te Petach-Tikva

"Technodaf"

Dit proefschrift is goedgekeurd
door de promotor prof.ir. L.H.J. Angenot.

Research Project
for
a D. Sc. Tech. Degree

July, 1972

SYNTHESIZING A TRANSPORTATION STUDY BY THE 'IN' PROCEDURE

YACOV ZAHAVI
Dipl. Ing.

Promotor
Professor ir. L. H. J. Angenot
Technische Hogeschool Delft

לאמא -

מוקדש בהוקרה

ENGINEERING LIBRARY

388.4
I13a
Engin

ACKNOWLEDGMENTS

The author of this dissertation wishes to express his appreciation and thanks to the many people who have been most helpful in accomplishing this project, and especially to:-

Prof. Wilbur S. Smith - whose extensive library and works were of great help to the author; Prof. R.J. Smeed - for his valuable remarks and suggestion to extend the project; ir. M. 't Hart, ir. A. Swiebel and ir. R. Sumedi - for supplying the author with information on the Amsterdam and Rotterdam Studies respectively; H.B. Barbe, Dipl. Ing. - for supplying the data for Zurich; and ir. J. Th. Gantvoort - who encouraged the author to continue with the project, and translated the summary into Dutch.

The author is thankful to his ex-secretary, Mrs. Miriam Danon, for her skilful typing.

Last, but far from least, I am grateful to my wife, Dahlia, daughter Nina and son Ron, for the encouragement which they have constantly provided, and patience they have shown with my spending much of their time on this thesis.

SYNOPSIS OF THE DISSERTATION

The efficient and safe movement of people and goods within an urban area is considered as essential for assuring the dynamic life and prosperous development of the area and its population;

The Transportation Study is recognized as a most important instrument for achieving the above objectives and in some countries is conditional for the approval of Federal or Governmental Aid for highway development in urban areas with more than a specified number of population;

The extensive development of the Transportation Study techniques during the last decade raised several crucial problems, such as the vast amounts of time, effort and money expended in the conduction of such studies. It has thus been concluded lately that a new approach is urgently needed, particularly for simplifying the procedures for data collection and processing;

The purpose of this Dissertation, therefore, is to analyze and develop new such procedures, by which Vehicular Traffic Patterns in an urban area may easily and rapidly be synthesized for a quick appraisal of the present or projected traffic demands, as well as for the evaluation of alternatives of road networks planned for the future;

The five principal components of the reasoning and procedure underlying the basis of this Dissertation may, thus, be summarized in the following way:-

The Statement: All known methods for travel analysis of existing patterns, or for forecasting travel demands for a target year, are based on the well-established phenomenon that travel patterns are recurring daily and may be explained and synthesized by the interaction of measurable parameters characterizing the urban area and its population;

The Hypothesis: Vehicular traffic patterns in an urban area may analytically be synthesized by applying a limited number of three basic area-parameters only, namely - Population, Motorization, and Area - resulting in comprehensive traffic data with sufficient accuracy for a first-approximation evaluation of current as well as projected travel patterns;

The 'IN' Model: Vehicles may be regarded as a new and separate population class in an urban area, with its own characteristic and inherent behaviour.

If this hypothesis is proven to be true, then a most distinct short-cut procedure may be developed, by-passing the complex analysis of numerous individual elements of trips in an urban area, and considering only the behaviour of the whole group of vehicles as a new population class in the area;

Object of the Thesis: To verify the Hypothesis and the Model, and formulate a simple procedure with the purpose of providing Town- Planners and City-Engineers with an analytical tool for practical applications;

Methodology: Deriving empirical relationships, by comparative analysis, from the available published data in Transportation Studies' reports, and integrating them within analytical formulation.

It is believed and hoped that this Dissertation has been successful in proving the Hypotheses, as well as in developing the so-urgently needed new procedures.

* *

E R R A T A

Chapter	Page	Line*	Original Text	Corrected Text
Glossary	(i)	21 t	is a town	in a town
Introduction	6	12 b	pupulation	population
"	7	17 t	sythetically	synthetically
"	7	20 t	analystical	analytical
Chapter 1	17	3 t	lenes	lanes
" 1	21	22 t	ovservations	observations
" 1	32	12 b	v/s	v/S
Chapter 2	37	12 t	agancies	agencies
" 2	41	12 t	rations	ratios
" 2	69	9 b	shuld	should
" 2	85	8 b	Copehagen	Copenhagen
" 2	86	7 b	that	than
Chapter 3	111	8 b	'R'	'Q'
" 3	117	7 t	over-spiling	overspilling
Chapter 4	118	11 b	towrds	towards
" 4	120	1 b	$= \sum_{j=1}^{n} \frac{P_j}{r_{ij}}$	$= G' \sum_{j=1}^{n} \frac{P_j}{r_{ij}}$
" 4	134	6 t	exes	axes
Chapter 5	151	20 t	develope	develop
" 5	151	9 b	intesity	intensity
" 5	154	5 t	mororization	motorization
" 5	164	18 b	expanded by	expanded for
" 5	185	6 t	oriteria	criteria
References	200	9 t	Graviatation	Gravitation

* 't' - from top of page

'b' - from bottom of page

CONTENTS

		Page
	Glossary	(i)
	Mathematical Symbols	(vi)
Introduction: The Transportation Study		
1.	Foreword	1
2.	The Transportation Study	2
3.	The Planning Process of a Transportation Study	4
4.	The Purpose and Scope of this Research	10
Chapter 1: The 'IN' Model		
1.	Introduction	13
2.	Principles of the 'IN' Model	15
3.	Computing Factors 'S' and 'C'	19
Chapter 2: The Daily Kilometrage 'K'		
1.	Introduction	36
2.	The Basic Relationships:	
	(A) Daily Trip Rates of Passenger Cars	43
	(B) Trip Lengths	53
	(C) Commercial Vehicles	59
	(D) Commercial Vehicle Trips	62
	(E) Taxi Trips	67
	(F) External Trips	69
	(G) The Total Daily Vehicle Trips	72
	(H) The Total Daily Vehicle Kilometrage	77
3.	The Procedure for Synthesizing the Kilometrage 'K'	81
Chapter 3: The Road Network		
1.	Introduction	90
2.	Freeways:	
	(1) The Length of Freeways	93
	(2) Lane-Length of Freeways	97
	(3) The Kilometrage on Freeways	99
	(4) Freeway Spacings	104
3.	Arterials:	
	(1) The Kilometrage - Road Length Relationship	108
	(2) Arterial Spacings	111
4.	Locals	
	(1) The Kilometrage - Road Length Relationship	115

		Page
Chapter 4: Traffic Models		
1.	Introduction	118
2.	The Gravity Model in Social Sciences	120
3.	An Example of Potential Fields	125
4.	Potential Fields of Population and Transportation Parameters	127
Chapter 5: Traffic on the Road Network		
1.	Introduction	151
2.	The Distribution of Kilometrage in an Urban Area:	
	(1) The Maximum Volume that can Enter a CBD	151
	(2) The Volume - Kilometrage Relationship	156
	(3) The Amsterdam Method	159
	(4) The α-Relationship Method	159
3.	Speeds on the Road Network	165
4.	The "IN' Model	174
5.	Synthesizing a Road Network	180
6.	Data for Economic Analysis	185
Chapter 6: Conclusions and Recommendations		
1.	The Need for Standard Definitions	188
2.	Applications and further development of the proposed Procedure	189
3.	The Need for further Analysis on the Road Networks	191
Postscript:		
	(1) The Jerusalem Transportation Study	195
	(2) An additional example of a Simplified Method	197
References:		199
Appendices:		
1.	Speed - Spacing Relationship	207
2.	A Computed Example of the Speed-Volume-Spacing Relationship	208
3.	Computing Factor 'C'	208
4.	The Study Towns	209
5.	Synthesizing the Transportation Studies of the Study Towns	211
6.	Computing the Potential Fields	235
7.	Potential Fields in per cent	241
8.	A summary of the Dissertation in Dutch.	243

Tables and Figures

Chapter	Table	Figure	Description	Page
Introd.		Plate 1	The Planning Process of a Transportation Study	5
1	1.1	1.1	Speed-Spacing Relationship	22/23
		1.2	An Example of the Speed-Volume-Spacing Relationship	27
		1.3	Average Speed-Spacing Relationship	29
		1.4	Average Speed-Volume Relationship	30
		1.5	The Factor 'C'	31
		1.6	Traffic Category of a City	33
		1.7	The Freeway Categories	34
2	2.1		The Study Towns:- General Information	38
	2.2		The Study Towns:- Trips	39
	2.3		The Study Towns:- The Road Networks	40
	2.4	2.1	Trip-Rates of Passenger-Cars vs. Motorization	45/46
		2.2	Trip-Rates related to Multi-Car Families and Distance from the CBD	47
	2.5	2.3	Trip-Rates of Passenger-Cars - Base Year	49/50
	2.6	2.4	Trip-Rates of Passenger-Cars - Target Year	51/52
		2.5	Trip-Length related to Population, USA	54
		2.6	Trip-Length related to Population, Study Towns	55
	2.7	2.7	Average Trip-Lengths - Base Year	56
	2.8	2.8	Average Trip-Lengths - Target Year	57/58
	2.9	2.9	Commercial Vehicles as percentage of Pass. Cars	60/61
	2.10	2.10	Comm. Veh. Trips vs. Number of vehicles	63/64
	2.11	2.11	Comm. Veh. Trips as percentage of Pass. Car Trips	65/66
	2.12	2.12	Taxi Trips as percentage of Pass. Car Trips	67/68
	2.13	2.13	External Trips related to Motorization and Area	70/71
	2.14	2.14	Total Daily Trips - Base Year	73/74
	2.15	2.15	Total Daily Trips - Target Year	75/76
	2.16	2.16	Total Daily Kilometrage - Base Year	77/78
	2.17	2.17	Total Daily Kilometrage - Target Year	79/80
	2.18	2.18	Synthesized vs. Given Kilometrage - Base Year	85/86

Chapter	Table	Figure	Description	Page
	2.19	2.19	Synthesized vs. Given Kilometrage - Target Year	88/89
3		3.1	Time-Space Diagram of a 'Green-Wave'	92
		3.2	Freeway Networks vs. Auto Registration, USA	94
	3.1	3.3	Freeway Networks vs. Pass. Cars, Study Towns	95/96
	3.2	3.4	Freeway Lane Length vs. Pass. Cars	97/98
	3.3	3.5	Kilometrage on Freeways	100/101
	3.4	3.6	Freeway Kilometrage Density vs. Lane Density	102/103
	3.5		Freeway Spacing Correction-Factor 'Q'	106
	3.6	3.7	Freeway Spacings	107/108
	3.7	3.8	Arterial Kilometrage Density vs. Road Density	109/110
	3.8	3.9	Arterial Spacings	112
	3.9	3.10	Arterial Spacings vs. Cycle and Speed of Green-Waves	113/114
	3.10	3.11	Local Kilometrage Density vs. Road Density	115/116
4		4.1	Cross-Sections of Population Potential and Volumes along Israel - 1961	126
		4.2	Screen-Lines in Tel-Aviv Area	128
	4.1	4.3	Screen-Lines Total Volumes, Tel-Aviv	
	4.2)	4.3)	Screen-Line 4-wheel Volumes, Tel-Aviv	
	4.3)	4.3)	Screen-Line Pass. Cars plus Comm. Veh. Volumes, Tel-Aviv	128/130
		4.4	Volume Patterns towards the Center	132
		4.5	Population Density towards the Center	133
		4.6	Potential Field of Pass. Cars, Tel-Aviv-Base	135
		4.7	" " " " " " " -Tar.	137
		4.8	" " "Employment, " " -Base	139
		4.9	" " " " " " -Tar.	141
		4.10	" " "Population, " " -Base	143
		4.11	" " " " " " -Tar.	145
		4.12	Average Cross-Section, Pass. Car Poten. Field	147
		4.13	Average Cross-Section, Employment Poten. Field	148
		4.14	Average Cross-Section, Population Poten. Field	149
5	5.1		Peak-Hour Volumes Entering Central Areas	154

Chapter	Table	Figure	Description	Page
		5.1	'Utilization Factor' of Town Centers	155
		5.2	Average Distance Travelled on some Imaginary and Real Road Networks	158
	5.2	5.3	The α-Relationship	161/162
	5.3		The Road Networks at Peak-Hour	167
		5.4	Speed-Volume Relationship - Freeways	168
		5.5	Speed-Volume Relationship - Arterials	169
		5.6	Speed-Volume Relationship - Locals	170
	5.4	5.7	The Total Road Network at Peak-Hour	172/173
	5.5	5.8	The 'IN' Number of Vehicles on the Road Categories at Peak-Hour	175/176
		5.9	The Total 'IN' Number on the Road Networks	177
	5.6	5.10	Synthesized vs.Given 'IN' Numbers	178/179
	5.7	5.11	Synthesized vs. Given Freeway Networks	181/183
6	6.1		Synthesizing the Jerusalem Transportation Study	196

G L O S S A R Y

ASSIGNMENT: The process by which trips from an origin zone to a destination zone are allocated to definite routes, based on factors known to influence route selection.

BASE-YEAR: The year at which all inventories of a Transportation Study are surveyed.

CALIBRATION: The process, usually mathematical, by which survey information is used to establish a relationship between two or more variables. A Traffic Model is considered as calibrated when it is capable of producing the original surveyed transportation or traffic patterns within acceptable levels of accuracy.

CAPACITY: The maximum number of vehicles that can pass over a given section of a lane or a road during a given time period under specific roadway and traffic conditions.

CAPACITY RESTRAINT: A process in which the travel resistance of a link in a transportation network is changed according to a relationship between the volume and its speed or other operational characteristics.

CATEGORY (of a road): The functional type of a road according to its standard of construction or its operational characteristics.

CBD: The Central Business District is a town, as defined by land-uses and their activity criteria.

CENTROID: An imaginary point at the center of a zone to which all the zone's characteristics are attributed.

COMMERCIAL VEHICLE: A motor vehicle which is used for the conveyance of goods in the course of trade or business, and is licensed as such.

CONCENTRATION: The number of vehicles occupying a unit length of a lane or a roadway at any given instant, and expressed in vehicles per kilometer.

CORDON: An imaginary line which completely encloses a given area and at which traffic counts and surveys are carried out.

EXTERNAL CORDON: The cordon delineating the boundaries of a Transportation Study.

CYCLE: The total time period required for one complete sequence of signal phase indications of a traffic-signal.

DISTRIBUTION MODEL: A mathematical process which produces a matrix of origin and destination trip transfer between pairs of zones, based on some aspect of their location and separation.

DYNAMIC LENGTH: The lane-length which is required to accommodate a given number of vehicles at a specified space-mean speed.

FLOW: The hourly representation of the number of vehicles that pass over a given section of a lane or a roadway for some period in less than one hour.

INTERRUPTED FLOW: A condition in which a vehicle traversing a section of a lane or a roadway is required to stop by a cause outside the traffic stream, such as signs or signals.

UNINTERRUPTED FLOW: A condition in which a vehicle traversing a section of a lane or a roadway is not required to stop by any cause external to the traffic stream, although vehicles may be stopped by causes internal to the traffic stream.

HEADWAY (average): The average interval in time between individual vehicles as they pass a given point on a lane or a roadway, as found by dividing the hour by the hourly volume.

'IN': The number of vehicles travelling on a road network at an Instant moment, whether moving or stopping because of traffic conditions.

INTER-ZONAL: Trips which have an origin in one internal zone and a destination in another.

INTRA-ZONAL: Trips which have both origin and destination within the same internal zone.

KILOMETRAGE: The value of the vehicle-kilometers of travel produced in specific areas and time periods, and computed by multiplying the number of trips by their trip-lengths on the road network, or by the volumes multiplied by the road-section lengths on which they are counted.

LANE: A strip of roadway intended to accommodate a single line of vehicles.

Free Lane: A lane free to serve moving vehicles.

LINK: An element in a network which connects two nodes.

MATRIX: An arrangement of values in the form of a table.

METROPOLITAN: The area surrounding a city if it represents a continuous extension of the city or if the people living there are pre-

dominantly connected with, and attracted to, the city in a close day-to-day economic and occupational sense.

MODAL SPLIT: The proportions of trips using various modes of travel, usually between public and private transport.

MODEL (Traffic Model): Mathematical relationships between two or more variables, which are able to reproduce the existing travel patterns, or synthesize the travel patterns for any desired future target year.

MOTORIZATION: A value defining the level of passenger-car ownership in the study area, and expressed in this Dissertation as the number of cars per 100 inhabitants.

NETWORK: A road, rail, bus or any other transport system used to carry and serve the travel demand.

NODE: A numbered point which defines the end of a link in a network. In the road network a node generally represents either intersection of routes or a zone centroid.

PARAMETER: A characteristic element of the urban area and its activities which may be related with other such elements for the purpose of explaining, or deriving by analytical methods, a known phenomenon.

PASSENGER CAR: A motor vehicle used for the transportation of persons and licensed as such, limited in capacity of seats (usually not more than six), for the personal and family use of its driver.

PATTERN: A general term denoting the travel characteristics in an urban area, such as the values and distributions of trips, volumes, kilometrage, speeds, and so forth.

PHASE: A specific part of the planning process.

TRAFFIC-SIGNAL PHASE: A part of the time cycle of a traffic-signal allocated to the movement of vehicles and/or pedestrians to ensure their safe passage.

POTENTIAL: The Potential produced at a point by a mass at a distance is defined as a constant times the mass and divided by the intervening distance between the point and the mass.

POTENTIAL FIELD: A graphical representation of equipotential contour lines of the sum of potentials over an area with many points and masses.

SCREEN-LINE: An imaginary line drawn across part of the study area, along which traffic counts or interviews are taken for control purposes for the calibration of the Traffic Model.

SOCIOECONOMIC (parameters): The characteristic parameters of the population known to affect their social and economic life in the study area, thus also affecting their travel behaviour.

SPACING: VEHICLE SPACING: The average interval in distance from head to head of successive vehicles, as found by dividing space-mean speed by the hourly volume of the moving vehicles on a lane.

ROAD SPACING: The distance between parallel roads of the same category, as measured between their centerlines.

SPEED: The rate of movement of vehicles, or a specified component of traffic, expressed in kilometers per hour.

Space-Mean Speed: Is the mean of the instantaneous speeds of vehicles passing along a stretch of road in a period of time.

Time-Mean Speed: Is the mean of the instantaneous speeds of vehicles passing a point on the road in a period of time.

SYNTHESIS: A mathematical process for computing the existing or expected traffic patterns in the study area, based on previously defined relationships between the characteristic parameters known to produce or affect those patterns.

TARGET YEAR: A chosen year at a future date for which a Transportation Plan is prepared. (Also called 'Design Year').

TRAVEL: The act of moving from origin to destination, combining a trip as an event with the property of Length and Time.

TRANSPORTATION STUDY: An engineering study with the purpose of planning optimal transportation facilities for a target-year, based on the travel demands expected at that year.

TRIP: The act of travelling between an origin and destination without respect to Length or Time.

TRIP RATE: The average number of trips per day per vehicle of a specific class, as found by dividing the total number of trips produced within the study area per day by the vehicles registered in the area, by their number.

TRIP LENGTH: The average distance of a trip in the study area, as found by dividing the total Kilometrage travelled by the total number of trips produced within the area in a day.

VEHICLE: Any component of wheeled traffic on roads, such as passenger cars, trucks, vanes, taxis, buses, etc.

VOLUME: The number of vehicles that pass over a given section of a lane or a roadway during a specific time period of not less than one hour.

VOLUME DENSITY: The ratio between the total daily kilometrage and the total length of free lanes in an urban area.

ZONE: (Traffic Zone): A basic unit of area for travel analysis, delineated with regard to local factors and criteria, such as the main road system, major barriers to traffic flow, and land use characteristics.

* * *

Mathematical Symbols used in this Dissertation

Chapter 1

n_i - The number of vehicles of class 'i';

a_i - The daily Trip Rate per vehicle of class 'i';

T - Total vehicle trips per day;

P_i - The proportion of vehicle trips of class 'i' at peak hour from the daily total;

T_p - The total vehicle trips at peak-hour;

T_{pi} - The total vehicle trips at peak-hour of class 'i' ;

$\bar{t}_i$ - The average travel time at peak-hour of vehicle class 'i';

IN_i - The INstant number of vehicles of class 'i' on the road - network at any moment of the peak-hour;

$\bar{d}_i$ - The average trip-length of vehicles of class 'i' at peak-hour;

$\bar{v}_i$ - The average space-mean speed of vehicles of class 'i' at peak-hour;

K_{pi} - The total vehicle Kilometrage of vehicles of class 'i' at peak-hour;

$\bar{v}$ - The average space-mean speed at peak-hour for the overall traffic;

K_p - The total peak-hour Kilometrage of all vehicle classes;

K - The total daily Kilometrage of all vehicle classes;

$L_j(\bar{v}_j)$ - The Dynamic Length of road category 'j' at the space-mean speed $\bar{v}_j$;

$\bar{v}_j$ - The average space-mean speed of the traffic on road category 'j';

L - The total Dynamic Length of roads of all categories;

$S_j(\bar{v}_j)$ - The average spacing between vehicles on a road category 'j' at a space-mean speed $\bar{v}_j$;

$IN_j(\bar{v}_j)$ - The INstant number of vehicles on a road category 'j' at a space-mean speed $\bar{v}_j$;

$S^o(\bar{v}_j)$ - The vehicle-spacing at a specific average space-mean speed $\bar{v}_j$ on a lane with the most efficient flow conditions;

$C_j(\bar{v}_j)$ - The coefficient by which $S^o(\bar{v}_j)$ should be multiplied in order to represent the vehicle-spacing on any other category 'j' of a road at the same speed $\bar{v}_j$;

K_{pj} - The vehicle Kilometrage travelled at peak-hour on a road category 'j';

K_{di} - The total daily Kilometrage of vehicle class 'i' on all the road categories;

β_j - The proportion of the total daily vehicle Kilometrage travelled on a road category 'j';

λ - The proportion of the total daily vehicle Kilometrage travelled at peak-hour;

$\bar{v}_s$ - Space-mean speed;

$\bar{v}_t$ - Time-mean speed;

k - The concentration of vehicles;

Chapter 3

L - Total length of free lanes

A - Land area, in sq.km.;

a - One side of a square area;

n - The number of free lanes entering an area;

S_p - The spacing of roads;

K_h - The vehicle Kilometrage at a specific hour 'h';

D - The lane density, km. per sq.km.;

M - The average number of lanes per road;

b - One side of a cell of roads;

Q - A correction factor for computing S_p for a limited number of road cells;

Chapter 4

F - The force of attraction;

m - The mass of a body;

r - The distance between two bodies;

G - The constant of gravitation;

$P_{i,j}$ - A group with 'i' or 'j' units;

r_{ij} - The distance between groups 'i' and 'j';

G' - A constant;

E - Energy;

$_{i}V_{j}$ - The potential which the group P_j produces at the point 'i' where the group P_i is located;

$_{i}V$ - The total potential at a point 'i' produced by the entire population of all groups;

Chapter 5

N - The number of vehicles that enter an area per hour;
f - The proportion of an area devoted for carriageways;
g - The proportion of the carriageways used for moving traffic;
w - The average width of a lane (meters);
I - The Kilometrage density, veh.km. per sq.km. ;
R - The road density, km. per sq.km.;
α - A constant ;
t - The total travel time on a road network at peak-hour;
t_s^p - The time saving between two alternatives of road networks.

INTRODUCTION: THE TRANSPORTATION STUDY.

1. Foreword

The city of today is a cauldron of boiling activities, demands, desires, and despair. It is the stage where opposing forces clash, conflicts collide, and vested interests fight. It is also the place where people wish - and hope - to live quietly and happily.

The most obvious external expression of the conflicts in the modern city is the one produced by the motorized traffic.

It is rather a sad paradox that the same motor-vehicle which brought about an acceleration of the dynamic processes in towns and enabled them to develop into cities that spread into huge metropolitan or megalopolitan areas, is now threatening the same cities with strangulation.

Moreover, the same motor-vehicle turned against its creator, and became a dangerous menace to Man, killing him, maiming him, or polluting his environment.

And the situation is deteriorating rapidly all over the world, since the levels of motorization, as well as the metropolitization, accelerate continuously, while the basic structures of spatial town-planning still remain within conventional and conservative frames.

It is true that many new and interesting ideas have been proposed during the last two-three decades for the modern structuring of cities. Some have even been experimented with, with arguable degrees of success. As yet, regretably, no ideal solution has been found, and the intensive search still continues.

One of the most important instruments for the optimal planning of towns for a future date is the General Town-Plan, or Master-Plan. Basically, it includes a thorough analysis of the past trends of development of the land-uses and population in the urban area, their projections to a future date, defining the objectives for a desired future urban condition, and then integrating the projected trends with the desired objectives into an optimal plan for the future development of the area.

Second in importance to a General Plan is the Transportation Plan, since it expresses the projected dynamic demands of the area and strives to satisfy these demands with the necessary transportation facilities.

Not only is the Transportation Plan based on the General Plan, but in most cases there is a close feed-back process between the two, where each one may affect the other, until a balanced condition is reached, for the most optimal Land Use - Population Transportation Plan.

This plan should consider, therefore, not only the physical aspects and development of the area, but its environmental values as well, for a better and safe life for its population.

In the following part of the Introduction a more detailed description of the Transportation Study is given, including its purpose, scope, and process of conduction and planning.

2. The Transportation Study.

Since the end of the second World War it has become apparent that the small scale planning of isolated transportation facilities is no longer adequate; the transportation demands for travel by ever increasing numbers of people and vehicles within the various parts of an urban area require the maximum utilization of all existing as well as planned facilities. It has therefore become necessary to consider the complete transportation system of an area when planning for the future. Thus the Comprehensive Transportation Study was initiated.

In the mid-Forties the studies were still sporadic, when basic techniques were explored and evaluated, such as the formulation of the Origin-and-Destination Survey. In the mid-Fifties the techniques were consolidated and the first of the extensive and comprehensive metropolitan Transportation Studies made their appearence in the United States, such as in Detroit (1953), to be followed by similar extensive studies in Washington (1955), Chicago (1956), Pittsburgh (1958), and so on.

The Basic procedures were then formulated by the Bureau of Public Roads, such as the "Manual of Procedures for Home Interview Traffic Study" (1954 and 1959), "Traffic Assignment Manual" (1964), "Traffic Assignment and Distribution for Small Urban Areas" (1965), etc.

Moreover, it was soon recognized in the USA that to ensure a rational and effective development of an urban area the comprehensive Transportation Study must be made obligatory. It was the late President Kennedy, in his message to Congress on "The Transportation System of Our Nation" (April 5, 1962) who had said:-

> "Highways are an instrumental part of any coordinated urban transportation program, and must be an integral part of any comprehensive community development plan. Accordingly, I have requested the secretary of commerce to make his approval of the use of highway planning funds in metropolitan planning studies contingent upon the establishment of a continuing and comprehensive planning process".

This objective was soon strengthened by the Federal-Aid Highway Act (1962, Section 134), and emphasized by the House of Representatives, Committee of Public Works report, which said:-

> "The Secretary of Commerce is directed to cooperate with the states in the development of long-range highway plans and programs coordinated with plans for improvement of other affected forms of transportation. This provision is applicable to urban areas of more than 50,000 population. The Secretary of Commerce (is further directed not to) approve any program after July 1, 1965, for projects in any urban area of more than 50,000 population unless he finds that such projects are based on a continuing comprehensive transportation planning process carried on cooperatively by states and localities".

Namely, the participation by the Federal Authorities in the expenditure for transportation projects was then preconditioned on the establishment and conduction of a comprehensive Transportation Study in urban areas as small as 50,000 population. This resolution gave the final impetus for a rapid spread of the Transportation Study as an instrument for urban planning not only in the United States but also all over the world. It was then finally and fully recognized that a comprehensive and continuing Transportation Study is a prerequisite for any coordinated and efficient development planning for an urban area. The mid-Sixties saw, therefore, hundreds of such studies being initiated and carried out all over the world.

However, the intensive prolification of such studies have raised several crucial questions and criticism as to the methodology of their conduction, since it had soon been realized that the standard procedures were very costly and time-consuming.

Moreover, it had soon become apparent that the techniques were rapidely developing in the direction of over-sophistication and over-elaboration. It has thus been concluded lately that a new approach is urgently needed, particularly for simplifying the tedious and lengthy phases of such a study.

This problem can best be summarized by Project 8-7 of the USA National Cooperative Highway Research Program (NCHRP), and presented in the Research Results Digest No. 27 (1971) on the subject of 'Evaluation of Data Requirements and Collection Techniques for Transportation Planning'. The purpose of this research project was stated as follows:-

> "Urban transportation planning studies require extensive amounts of data on population, travel, transportation facilities, land use and the various socioeconomic characteristics. Techniques for obtaining these data are costly and time-consuming. In view of the evolving nature of the transportation planning process, A reexamination of data requirements and collection techniques has been needed".

Among the many important conclusions and recommendations presented in this Research Results Digest, the following are of particular interest, since they practically summarize the approach which underlines the basis of this Dissertation:-

"(1) The times required to collect and process data are excessive, averaging at least two years. Methods to speed up data collection, especially data processing, are badly needed:

(2) Basically, strategic transportation plans are prepared on the basis of estimates, not data. Errors of estimates are likely, as a general rule, to be much larger than data errors. Gathering more data than are needed to establish the values of the estimating equations is apt to be unproductive".

The author of this Dissertation, after 20 years of extensive work in Transportation and Traffic Engineering, even with the most sophisticated procedures and Traffic-Models, had already arrived at the same conclusion several years ago and in 1969 initiated the subject of the thesis presented in this Dissertation, with the aim of developing the so-needed and called for new methods. The Hypothesis developed in this research is based, therefore, on the assumption that Vehicular Transportation Paterns in an urban area may analytically be synthesized by applying a limited number of available basic area parameters, resulting in comprehensive transportation data with sufficient accuracy for a rapid and first-approximation evaluation of existing, as well as projected, transportation patterns.

However, to better understand the basic problem, as well as to introduce the procedures and terminology currently in use, a short summary of the standard Planning Process of a Transportation Study is presented in the following paragraph.

3. The Planning Process of a Transportation Study.

The Transportation Planning Process represents the integration of many interacting characteristics of the urban environment. Plate 1 shows the principle elements participating in the process, where the columns present the major phases of the work, while the rows present the principal factors which are required for each phase.

Of necessity, the following review is cursory and will touch upon the crucial parts only, although many variations on the same theme may be found in the technical literature on the subject of transportation planning.

It should be noted, however, that the preliminary phase, not even shown in the diagram, is the one defining the general objecttives of the Study: its scope and techniques; limiting its area and dividing the study

THE PLANNING PROCESS OF A TRANSPORTATION STUDY

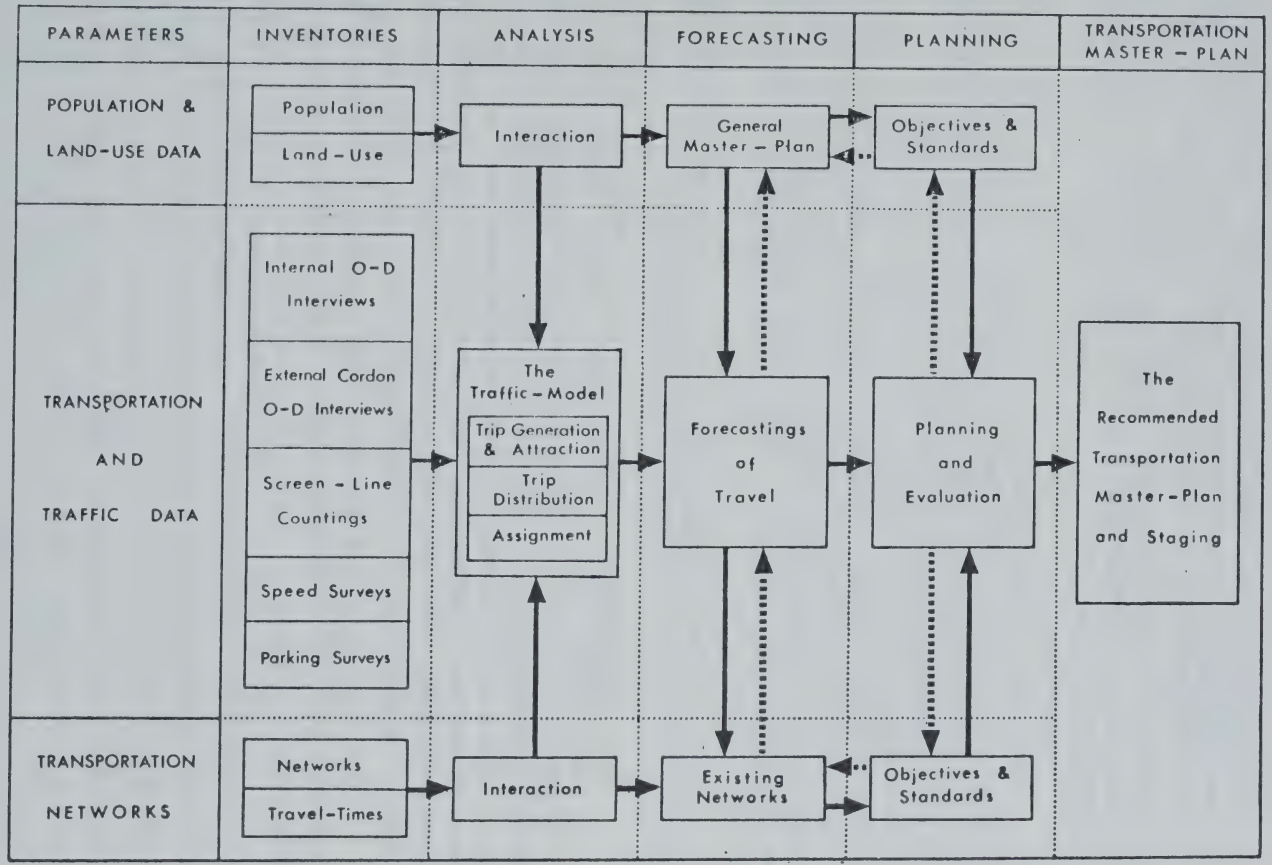


PLATE 1

area into traffic zones; and restricting it within a specified budget and duration.

The first phase is, then, the technical definition of the parameters which are to be gathered and analyzed. These parameters, or variables which are believed to be interacting and affecting the travel patterns, are usually classified into three broad groups: (a) Population, and Land-Uses which serve it; (b) Transportation and Traffic Data; and (c) The Transportation Networks.

Each group is then further classified into detailed classes. For instance, the Population is further classified by levels of income and other such socioeconomic criteria; the Land-Uses are classified by their uses and activities, such as Commerce, Industry, Residence, etc.: The Transportation and Traffic Data is classified into the modes of travel, such as Public-Transport trips, Passenger-Car trips, Commercial-Vehicle trips; Volumes and Speeds; etc., and the Networks are defined according to their mode of use such as Public-Transport Networks (bus, railway, underground railway, etc.) or Categories of Roads, such as Freeways, Arterials, Locals, etc.

These precise definitions are most important and even decisive, since all the forthcoming surveys must abide by them.

The second phase, and one of the most crucial and sensitive parts of a Transportation Study, is the Inventory of the existing conditions of the approved parameters. This phase, of data collection, is carried out mostly by field surveys, to provide the basic information necessary for the determination of the existing travel characteristics (and facilities), and including the basic problems of WHO makes the trips, from what ORIGIN to what DESTINATION, for what PURPOSE, by which MODE, at what TIME of the day, what is the DURATION of the trip. and so on.

The most important survey is still recognized to be the Home-Interview, where a statistical sample of the internal pupulation of the study area is interviewed and the answers are then expanded to represent the travel behaviour and socioeconomic information of the total population. The transportation data is gathered from several sources, such as from the Home-Interview and public transport Origin-Destination (O-D) surveys; a supplementary O-D survey at the external Cordon around the study area; Screen-Line countings of the crossing vehicular or passenger volumes; Speed and Travel-Times on the Networkds; and even Parking surveys at selected locations such as at the Central Business District (CBD) or other congested areas. At the same time the transportation Networks are defined precisely (Coded), including their physical characteristics and the travel time on them.

The above Inventories present, therefore, a picture of the study area's transportation and traffic patterns at one point in time (although the individual surveys may be carried out during several months). The information obtained from the above surveys, together with the information on land-uses (received from the General Plan or from a separate survey), must then be further analyzed in order to obtain those relationships upon which not only the existing patterns can be explained and reproduced by analytical methods, but upon which the future patterns may be predicted with a high level of confidence. Thus we come to the Analysis phase of the work.

The third phase. Analysis, strives therefore to formulate the basic relationships which explain the travel patterns within the study area during an average week-day. This is done be a mathematical analysis of the interacting parameters which are believed (and known from past experience) to influence and affect the travel patterns. The result is the Traffic-Model, which is a set of mathematical equations that are able to reproduce sythetically the existing base-year travel patterns, or synthesize the travel patterns for any desired target-year, based on the input parameters which are expected to occur in the future.

Thus, the Traffic-Model is an analystical tool for forecasting travel patterns with a high level of confidence.

The Traffic-Model usually includes three separate parts:

(1) The Trip Generation and Attraction Model; which is able to compute the number of generated and attracted trips for each traffic-zone, by applying their characteristic parameters, such as those of the population for the generated trips and those of the land-uses for the attracted trips;

(2) The Distribution Model; which can produce a matrix of O-D trip transfer between pairs of zones, based on some aspect of their location and separation, such as distance, travel-time, or cost of travel between them. There are many such Distribution Models, which may be classified into two main groups, according to the logical basis underlying their application, especially for a target-year:
(a) Analogy Models: which distribute the trips according to 'Growth Factors' computed on the basis of the projected parameters of the study area. There are several such models, such as the Uniform Factor, the Average Factor, the Detroit Method, Fratar Method, and so on. (b) Synthetic Models; which synthesize the expected distribution by applying the analytical relationships that explain the base-year distribution by the interaction of the area's parameters. This group contains the Gravity Model, the Interactance Model, one

of several Opportunity Models, or miscellaneous models based on the cost of travel, etc.

At this stage, however, the matrix of trips expresses the "Desire-Lines' namely the airline distribution of the trips between the traffic zones, with no regard to the actual transportation networks.

(3) The Assignment Model; which allocates the trips between pairs of zones and assigns them to definite routes in the transportation networks, based on factors known to influence route selection. For instance, along the 'minimum path', namely along the route with the minimum resistance to travel, such as the minimum travel-time or the minimum total cost of travel.

Assignment Models may be classified into two main groups: The 'All or Nothing' procedures, where all trips between a pair of zones are allocated to the absolute minimum path; and the 'Capacity Restraint' procedures, which allocate the trips between several routes, depending upon the instant relative (and even ever-changing) values of their travel resistance.

Each one of the many models has its own advantages and disadvantages, and the choice between them depends much on the previous experience and personal taste of the responsible person in charge of the study.

This phase of the analysis and development of the Traffic-Model concludes with the calibration of the model, namely when it can produce the base-year traffic patterns within acceptable levels of accuracy.

It should be mentioned here that the analysis, and especially the development of the Traffic-Model and its use, lean heavily on the application of modern high-speed electronic computers.

The fourth phase is that of Forecasting the future characteristics of the study area, including its population and land-uses, levels of vehicle ownership, and the various socioeconomic parameters, all of which were found to influence the travel patterns.

When all the necessary parameters have been projected to a chosen target-year, the Traffic-Model can then be put into use. The first stage is the estimation of the future travel demands in the area, based on its development characteristics, and expressed by the expected number of generated and attracted trips for each zone. The Distribution and Assignment stages are then carried-out on the base-year Networks, as an intermediate stage, in order to locate the critical parts of the existing networks which are likely to be overloaded in the future, and to define the Demand - Capacity ratios and the deficiency in transportation facilities in those parts.

The emerging picture may then give the planner a better indication as to what might happen in the urban area if no strategic planning is done for the transportation networks and facilities; At the same time it also gives an indication as to what might be needed to satisfy the future travel demands.

An additional intermediate stage is the introduction of the Modal-Split ratio, which is the division of person trips between Public and Private transport. The Modal-Split for the future - expected or desired - can be introduced at any one of the three parts of the Traffic-Model, depending on the procedure prefered; - at the Generation and Attraction, the Distribution, or the Assignment parts.

The fifth phase is the planning of alternatives of transportation networks and facilities, to cope with the expected future travel demands. Since in most cases the three parts of the overall Traffic-Model are interwoven and may affect each other by a feed-back process (when each one of the assumed networks may affect and produce its own characteristic distribution of trips), the planning process is of an iterative nature, in which the original assumptions may have to be revised and tested again. This process is repeated by assuming different alternatives of transportation networks (which may also be affected by changing the objectives and standards of their planning) until a satisfactory equilibrium and consistency are reached between the input data and the final results.

This equilibrium stage is usually reached when the economic analysis has shown which of the several alternatives is the optimal one by considering the Total Cost and Benefits of the system, as well as its environmental value.

In the final sixth phase the recommended Transportation Master Plan can be formulated and presented in its final form, including the most effective staging of its implementation over the years. Since the target-year is usually about 20 years ahead, the staging is broken-down into about 5-year periods.

At this stage, however, a most critical point must be raised: The whole planning process described above had been based on the assumption that the future development of the study area will follow in the steps of the desired projections or plans. But will it?

Since past experience had shown that in most cases the actual development differed, to various extents, from the planned one, two important conclusions may be drawn from this trend: (a) That the recommended plan should be as flexible as possible, with the capability of being changed, with minimum adjustments and cost, to cope with the possible changing conditions; and (b) That the planning process should be

a continuous one, preferably done by the establishment of a permanent agency, which will continuously update the estimated future travel demands with the new development trends in the area, and periodically adjust the recommended basic plan to cope with the new changing conditions.

4. The Purpose and Scope of the Research.

As already mentioned above, the complexity of current methods for data gathering and processing in a Transportation Study urgently require the development of new, easy and rapid, procedures.

The purpose of this Dissertation, therefore, is to search for such new methods, formulate their basic logic, test their validity and accuracy, and define their systematic procedures for practical application.

It should be noted and emphasized, however, that this Disseration deals with only one component of the total transportation system, namely that of the Vehicular Traffic and the Road Networks serving it. Nevertheless, this one component can fully be formulated and analyzed within the scope of this research, as an independent subject.

It is only natural to expect, however, that further research will be carried out in this field with other modes of transport, and the author hopes that he will have the opportunity to do so in the near future.

This Dissertation may be seen, therefore, as a complete work by itself, since it encompasses most - if not all - of the basic factors encountered while analyzing vehicular travel patterns, as well as planning the road networks to serve them.

The analysis in this research is based on the comparative analysis of vehicular travel data presented in the published reports of 34 Transportation Studies for towns from 4 continents, covering a wide range of pupulation and motorization. For base-year data, for example, the range of population is from 74,000 and up to over 8.8 million, and the range of motorization is from less than 1 passenger-car per 100 inhabitants and up to over 40.

It should be observed, however, that in no way does the analysis in this Dissertation criticize or evaluates the significance or value of the travel analysis or recommended network plans presented in the reports; It rather limits itself to show that the existing - or projected - travel patterns in urban areas, as well as the recommended Transportation Plans based on the current philosophy of planning, may be easily and rapidly synthesized by a simple Model and a straightforward procedure, within acceptable levels of accuracy.

The following chapters present, then, the full methodology of the research, results, conclusions, and recommendations.

In Chapter 1 the principal Hypotheses are presented, the 'IN' Model is formulated, and its parts are explained.

Chapter 2 includes a comparative analysis of the basic data published for 34 towns, where simple relationships are derived for the vehicular parameters, including the number of vehicles, the number of trips they produce, and their total daily Kilometrage. The chapter concludes with a proposed procedure for synthesizing such data for any given urban area for which only 3 basic parameters are known:- Population, Motorization, and Area. A comparison between the synthesized versus the given data shows that the results are within acceptable levels of accuracy.

Chapter 3 deals with the problem of distributing the total daily Kilometrage on the various categories of roads in urban areas, and several interesting relationships are being developed, by which the total Road Network may be synthesized easily and rapidly.

Chapter 4 begins with a short review of the development history of the vectorial Distribution Traffic-Model and then continues with the concept of the scalar Potential Field Model, by which the total daily Kilometrage may be distributed spatially over the urban area, to represent the actual micro-conditions of Volumes and Kilometrage.

Chapter 5 continues to develop the principal relationships of traffic distribution within an urban area, introduces the additional parameter of Speed, and then comes back to a more thorough analysis of the 'IN' Model. The chapter concludes with a proposed procedure for synthesizing Road Networks by new methods developed in this research.

Chapter 6 presents the conclusions derived from the research, as well as proposes several recommendations for the future continuation and development of the ideas and procedures expounded in this Dissertation.

* * *

CHAPTER 1 - THE 'IN' MODEL.

1. Introduction.

Life in an urban area is a closed and orderly system, with a frequency of 24 hours; there are, of course, characteristic variations between the days, particularly at the week-end, but the population activities during an average week-day are quite regular and stable.

Since travel reflects the dynamic aspects of an area's activities, all known methods for travel analysis and projections are based on the already well-established phenomenon that travel patterns are recurring daily.

The current methods of travel analysis are based, therefore, on the thorough analysis of the population's daily behaviour, where trips by each mode of transport are surveyed and then summarized according to their basic components, such as Origin and Destination, Purpose of trip, Time of day, Duration of trip, etc.

Moreover, for achieving a better insight into the reasons why trips are produced, part of the data, especially that which is derived from the Home Interview, is further stratified by the socioeconomic parameters of the trip-producers, such as family size, levels of income, motor vehicle ownerships, professions, and so on.

The main objective of the analysis and the Model building, therefore, is to formulate the relationships between the interacting parameters which are believed, or known from past experience, to influence trip production, attraction and distribution.

In short, since a Transportation Study is being done "By the People For the People", the approach is primarily based on the direct questioning of the population, whether by the Home-Interview, Cordon Driver Interview, Commercial or Taxi Driver Interview, Public Transport Passenger Interview and so on.

However, such surveys are time-and-money consuming, since millions bits of information have to be collected, the results have to be formulated and tested by complex methods of analysis, and Traffic-Models have to be developed and calibrated. Thus, even if a Vehicular Traffic-Model is being developed, it is done so from the raw answers of the population interviews, whether at home or behind the steering -wheel.

Moreover, while the coprehensive transportation studies for vehicular travel begin with surveys of personal-questioning of the population, their end-results are always volumes of vehicles travelling on the networks of roads at certain speeds.

Therefore, if these volumes and their distribution could directly be defined by their relationship with some basic parameters of the study area, much effort would be saved by such a short-cut method.

It is of interest to note that this short-cut approach has been tried time and again by traffic analysts during the last several years, with the aim of developing a simplified, useful, tool for quick first-approximation analysis of metropolitan areas' traffic demands (as will be detailed later on). However, most - if not all - such methods have been based on the assumption that Origin- Destination matrices of trips are already available; namely, results of interviewing the population.

The basic assumption in this thesis has been, therefore, that a Model to represent vehicular travel patterns in an urban area may be directly developed from just three simple parameters of any urban area, namely: Population, Motorization, and Area. Thus, such a Model will eliminate the present need to interview the population.

The above assumption is based on the Hypothesis that vehicles in an urban area may be regarded as a new and separate population class in the area, with its own characteristic and inherent behaviour patterns, as produced by the above three parameters.

If this Hypothesis is proven to be true, a most distinct short-cut procedure may then be developed, by-passing the complex analysis of numerous individual elements of trips within the urban area, and considering only the behaviour characteristics of the whole group of vehicles, as a separate class in the area.

In the next paragraph this basic hypothesis will be developed into a mathematical formulation of the 'IN' Model, based on the INstant number of vehicles moving on the network of roads at peak-hour.

* * *

2. Principles of the 'IN' Model.

The basic idea of the first part of the proposed 'IN' Model is based on the conception of the Dynamical-Length of traffic lanes required to satisfy traffic demands for the INstant number of vehicles at peak-hour.

The formulation of the basic equation is, therefore, quite simple, as follows:-

(1) Let: n_i - be the number of vehicles of class 'i' in the study area, where $i = 1,\ldots,m$;
a_i - be the average Trip-Rate per vehicle of class 'i' per day;

The experience in many towns has shown that the number of vehicle trips 'T' may be approximated by -

$$T = \sum_{i=1}^{m} n_i \times a_i \quad ; \qquad (1.1)$$

The argumentation is that the number of trips made within the urban area by external vehicles (i.e., registered elsewhere) equalizes approximately the number of trips made outside the urban area by internal vehicles. More about this assumption is discussed in chapter 2, sub. 2F.

(2) Let: P_i - be the proportion of the vehicle trips of class 'i' at peak-hour from the daily total;
Then: The total vehicle trips at peak-hour, T_p, is -

$$T_p = \sum_{i=1}^{m} T_{pi} = \sum_{i=1}^{m} n_i \times a_i \times p_i ; \qquad (1.2)$$

(3) Let: $\bar{t}_i$ - be the average trip travel-time at peak-hour of vehicle class 'i' (where $\bar{t}_i \leqslant 1$ hr.);
Then: The INstant number of vehicles of class 'i' on the road network at any moment of the peak-hour - assuming a uniform distribution of the trips during that hour - is:

$$IN_i = \bar{t}_i \times T_{pi} \quad ; \qquad (1.3)$$

As in regard to the units of measurement in this formula, it follows that:-

$$\text{hr.} \times \frac{\text{veh. trips}}{\text{hr.}} = \text{veh. trips};$$

However, since the meaning of 'veh. trips' in this case is the number of vehicles that enter the road network at peak-hour, it may be regarded as the number of 'vehicles'

only, thus equalling the unit of measurement of the number of vehicles at an INstant moment on the road network.

In other words, the numerical value of the IN number of vehicles of class 'i' equals the accumulation of the number of vehicles entering the road network and leaving it during the time-duration of an average trip.

(4) Let: $\bar{d}_i$ - be the average Trip-Length of vehicles of class 'i' at peak-hour, in km.;

$\bar{v}_i$ - be the average space-mean speed of class 'i' at peak hour, in kph.;

K_{pi} - be the total vehicle Kilometrage of class 'i' at peak-hour, in veh.km.;

Then:-

$$IN_i = \bar{t}_i \times T_{pi} = \frac{\bar{d}_i}{\bar{v}_i} \times T_{pi} = \frac{K_{pi}}{\bar{v}_i} \; ; \qquad (1.4)$$

It should be noted that the numerical value of the IN number equals, therefore, the vehicle-hours of travel on the network during the peak-hour, although the units of measurement are different: (veh.) for the IN number and (veh.hr.) for the travel-time.

(5) Let: $\bar{v}$ - be the average space-mean speed at peak-hour for the overall traffic flow;

K_p - be the total peak-hour Kilometrage of all vehicle classes (where K is the total daily Kilometrage of all vehicle classes);

Then:

$$IN = \sum_{i=1}^{m} \frac{K_i}{\bar{v}_i} = \sum_{i=1}^{m} \frac{K_i}{\bar{v}} = \frac{1}{\bar{v}} \sum_{i=1}^{m} K_i = \frac{K_p}{\bar{v}} \; ; \; (1.5)$$

(6) Let: L - be the Dynamic Length of all road categories, where for each category 'j' ($j = 1, \ldots, r$) there is an average space-mean speed $\bar{v}_i$ at peak-hour;

Then:-

$$L = \sum_{j=1}^{r} L_j(\bar{v}_j) \; ; \qquad (1.6)$$

(7) Let: $S_j(\bar{v}_j)$ - be the average Spacing of vehicles on a road category 'j' at a space-mean speed $\bar{v}_j$;

Then;-

$$L_j(\bar{v}_j) = IN_j(\bar{v}_j) \times S_j(\bar{v}_j) \; ; \qquad (1.7)$$

This is to say that the Dynamic Length of lenes equals the INstant number of vehicles at the average speed $\bar{v}$ multiplied by the average Spacing between them at that speed.

(8) Let: C_j - be the Coefficient by which the Spacing S^o at a specific average speed $\bar{v}_j$ on a lane with the most efficient flow conditions (Freeway category '2', as detailed in the next paragraph) should be multiplied in order to find the Spacing of any other category 'j' of a road at the same speed $\bar{v}_j$;

Then:-

$$S_j(\bar{v}_j) = C_j(\bar{v}_j) \times S^o(\bar{v}_j) \; ; \qquad (1.8)$$

In other words, C_j is the function by which the Spacing S^o has to be adjusted in order to represent the Spacing S_j for a road category 'j' for any given average speed $\bar{v}_j$.

(9) Let: K_{pj} - be the Kilometrage travelled at peak-hour on a road category 'j' ;

Then: By incorporating Formulas (1.5) and (1.8) in (1.7), the Dynamic Length of the road category 'j' will be:-

$$L_j(\bar{v}_j) = \frac{K_{pj}}{\bar{v}j} \times C_j(\bar{v}_j) \times S^o(\bar{v}_j) \; ; \qquad (1.9)$$

(10) K_{pj} may be derived in the following way:

Let: K_{di} - be the total daily Kilometrage of vehicle class 'i' on all the road categories;

β_j - be the proportion of the total daily Kilometrage travelled on a road category 'j';

λ - be the proportion of the total daily Kilometrage travelled at peak-hour;

Then: - $K_{di} \times \beta_j$ equals the total daily Kilometrage of vehicle class 'i' on a road category 'j'; (1.10)

Hence, $\sum_{i=1}^{m} K_{di} \times \beta_j$ equals the total daily Kilometrage (1.11)
on the road category 'j';

It follows, then, that -

$$K_{pj} = \beta_j \times \lambda \times \sum_{i=1}^{m} K_{di} \; ; \qquad (1.12)$$

(11) By substituting Formula (1.12) in (1.9), it follows that -

$$L_j(\bar{v}_j) = \left(\frac{\beta_j \times \lambda}{\bar{v}_j} \times \sum_{i=1}^{m} K_{di} \right) \times \left(C_j(\bar{v}_j) \times S^o(\bar{v}_j) \right) \; : \qquad (1.13)$$

(12) The Total Dynamic Length of lanes for all road categories is, therefore:-

$$L = \sum_{j=1}^{r} \left[\left(\frac{\beta_j \times \lambda}{\bar{v}_j} \times \sum_{i=1}^{m} K_{di} \right) \times \left(C_j(\bar{v}_j) \times S^o(\bar{v}_j) \right) \right] \qquad (1.14)$$

Thus, by assuming, at this stage, that the Kilometrage K_{di} is distributed on the road categories proportionally to the total K_d, and that the same distribution holds true at the peak hour, it follows that the total Dynamic Length of lanes equals the sum of the peak-hour Kilometrage on the 'j' categories of roads, divided by the respective average space-mean speeds, and multiplied by the respective Spacings.

At this stage a surprising result should be pointed out. When submitting actual data from transportation studies in Formula 1.4. the INstant number of vehicles at any moment of the peak-hour is very low. about 6 - 15 per-cent only of the total number of vehicles in the area.

Just to name one example: - When the results of the Tel-Aviv Transportation Master-Plan (Ref. 1.1.) were submitted for passenger cars for base-year 1965, Where:

Passenger-Cars	-	39,643
Trip Rate	-	7.83
Percentage of trips at peak-hour		8.1
Trip Length, km.	-	4.1
Average speed, kph.	-	28.0

Then the IN number is:

$$IN = 39,643 \times 7.83 \times 0.081\frac{4.1}{28.0} = 3,680 \ ;$$

i.e., the IN number is 9.3 per cent only of the total 39,643 registered passenger-cars in the study area.

Even by assuming that at a maximum instant-moment of the peak hour the volume on the whole network is as much as 25 per cent above the average uniform volume for that hour, even then the number of vehicles would not amount to more than a maximum of 18 per-cent only. (Peak 15-mins. volume is within 27-31 per-cent of the peak-hour volume for a single road, or by 8-25 per cent more than the uniform average. Ref. 1.2.).

This appears, at first glance, to be rather a surprising result, since the impression at the peak hour is that a much higher percentage of the total number of vehicles is on the road network at that time. The fact is, however, that only a small percentage of the total vehicle population is on the road network between points of Origin and Destination even at peak hours, although it is this negligible percentage that creates the tremendously difficult problems of the peak-hour traffic.
Further examples of computing the IN number will be detailed in Chapter 5.

To compute Formula 1.14 several parameters have to be defined, namely 'K' - the total daily Kilometrage; as well as $C_j(\bar{v}_j) \times S^o(\bar{v}_j)$ - the average Spacing between vehicles - which is a function of speed '$\bar{v}_j$' on a lane with the most efficient traffic conditions - and the lane Capacity Factor 'C_j' - which depends on the design and operational standards of a specific category of roads.

In the following paragraph the last two parameters will be discussed, and their numerical values will be computed, while the 'K' value will be computed in the next chapter.

A further development of the complete 'IN' procedure will be presented at a later stage, after the various factors affecting Formula 1.14 will be evaluated.

3. Computing the 'S' and 'C' Factors.

(1) One of the fundaments of Traffic Engineering is the understanding of the interrelationships between the basic parameters of traffic flow for various road and traffic conditions.

During the past two decades numerous studies have been carried out all over the world with the purpose of establishing and defining such relationships, which then were presented in many different forms, such

as Speed-to-Volume relationship, Speed - Concentration, Speed - Spacing or Speed- Headway, Headway distributions, Travel Time - Flow, etc.

Although Volume may be regarded as the most significant measure of traffic demand on a facility, Spacing and Headway affect the driver's choice of speed and position withing the traffic flow. Thus, much of the earliest work in Highway Capacity has assumed Spacing between vehicles as an important criterion. However, vehicles do not move at uniform spacing, but tend to form groups, even at quite low volumes, and thus individual spacings or headways show a large variation, with many vehicles queuing at short spacing/headway, while others are separated by relatively large distance or time gaps.

Much has been written on the application of mathematical models to Headway and Flow relationships, such as the Poisson Distribution, a Modified Poisson or Composit Distribution, various Queuing Models, as well as applying sophisticated Analogy Models of various sciences, such as Physics, Dynamics, Hydraulics, and so on. (For example, Ref. 1.3-4-5-6-7).

The understanding of flow behaviour has become even more complex by limiting each study to a specific assumption or condition. Just to name one; while Spacing (which is the reciprocal of Concentration) describes the condition along a length of roadway rather than at one given point, Headway, on the other hand, better describes point conditions. Thus, one study might present spacing along a road section, as derived from hourly volume and speed measurements, while another study might present the minute distribution of headways at a specific point of the same road section, such as at the entrance - or exit - of a signalized intersection. It is quite obvious, therefore, that although spacing and headway, as such, can be related by a most simple relationship, namely - Headway (sec.)=Spacing (m)/Speed (m/sec.), it is quite questionable whether the results of two such studies can be compared by transforming either one of them into the other's spacings or headways.

Moreover, if Speed-Volume or Speed-Concentration studies are considered, they too may be carried out by full hourly measurements of volume or speed, thus representing hourly averages, or they may be carried out by short-time measurements of platoons only of vehicles, where the minute rates of flows and speeds are then transformed into hourly relationships. It is quite clear, therefore, that these two different methods of measurement might give different results for the same traffic on the same road section.

Moreover, many of the Speed-Volume and Speed-Concentration studies have been carried out for uninterrupted flow conditions, since it is most difficult to isolate these relationships under interrupted, unstable, flow conditions.

Delay Time - Flow measurements, on the other hand, are mostly carried out for interrupted flow conditions, such as at - or between - signalized intersections.

In consideration of such few factors, out of many other, it becomes understandable why much caution should be exercised when comparing the results of various traffic studies, carried out by different methods, for different research purposes.

(2) A most comprehensive source for Speed-Volume or Speed-Concentration relationships is the monumental publication - 'Capacity Manual - 1965' (Ref. 1.8), where many such studies are graphically presented.

A serious limitation of the data presented in that publication is that the studies have been carried out by many different methods, as has already been mentioned above.

Figure 3.37 of that book (p.61) can be cited as a typical example:- One curve in that Figure, that for the Ford Expressway in Detroit, represents the minute rate of flow and average speed for all the minutes in a day for the median lane, while the curve labeled Chicago in the same Figure represents aggregate hourly volume and speed data for all lanes from two separate sections of the Eisenhower Expressway and for one lane each of the Edens and Calumet Expressways. The third curve in the same Figure, labeled Los Angeles, is based, however, on 5-min. volume and speed ovservations for all lanes in one direction on the six lane Santa Anna Freeway during two evening peak periods.

It can be assumed, therefore, that results of some studies may be in disagreement - if not contradictory - to other studies. It should be borne in mind, then, that any comparison between the various studies presented in that publication, or any other one, should be subjected to a most cautious evaluation.

In spite of all these limitations it was intuitively assumed that the different methods of measurement might affect quantitatively only the traffic flow relationships, while the qualitative aspects of the various road categories might remain distinct and unaffected.

With this consideration in mind, all the Speed-Volume or Speed-Concentration studies of that publication were concentrated into one graph, as presented in Fig. 1.1. This figure includes some additional results as well, from studies carried out in London, Ipswich and Tel-Aviv (Ref. 1.1.; 1.9; 1.10).

At this stage it should be noted that the Speed-Spacing relationship is outmoded now, thus all study-results are presented in the 'Capacity Manual', or any other current publication, in all other possible combinations but the one in the form of Speed-Spacing relationship. Since, on the other

hand, it is the Speed- Spacing relationship that has to be analyzed in the light of Eq. 1.9, all other combinations have been transformed into that relationship, as presented in Fig. 1.1.

It should also be mentioned that since all relationships in the 'Capacity Manual' and other sources have been presented in a graphical form only, the graphs had to be transformed into numerical data, as presented in Appendix 1, and shown in Fig. 1.1 in metric units.

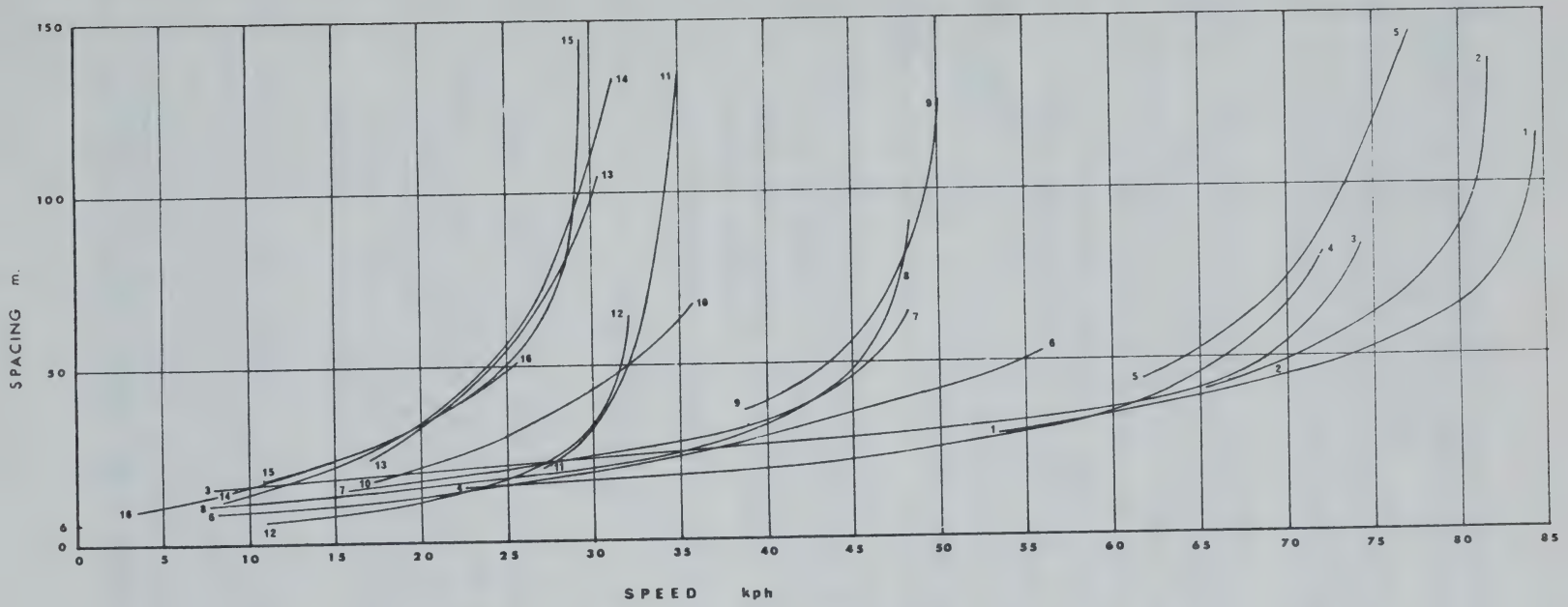
The studies in this figure cover a wide range of road categories, from CBD (Central Business District) Streets and up to Freeways, as well as for all possible flow conditions, namely for Uninterrupted Flows - marked by (U), Interrupted Flows (I), and Intermixed Conditions as found on typical urban networks (M).

The full list of studies presented in that figure is detailed in Table 1.1.

Table 1.1

Speed - Spacing Relationship

Curve	Study	Flow Type	Reference
1	Los Angeles Freeway	U	1.8 - Fig. 3.37
2	Detroit Freeway	U	1.8 - Fig. 3.37
3	Chicago Freeway	U	1.8 - Fig. 3.37
4	Hollywood Freeway	U	1.8 - Fig. 3.50
5	Eisenhower Expressway	U	1.8 - Fig. 3.49
6	Lincoln Tunnel	U	1.8 - Fig. 3.48
7	New Haven - Urban	I	1.8 - Fig. 3.54
8	Merritt Parkway	U	1.8 - Fig. 3.51
9	Chicago - Urban, without parking	I	1.8 - Fig. 3.46
10	Tel-Aviv - CBD, high quality sections	M	1.1 - Fig. 6.4
11	Chicago - Urban, with parking	I	1.8 - Fig. 3.46
12	Chicago - Urban	I	1.8 - Fig. 3.54
13	Tel-Aviv - CBD, medium quality sections	M	1.1 - Fig. 6.4
14	London - CBD Streets	M	1.9 - Fig. 2
15	Simulation - Urban signalized Intersection	I	1.8 - Fig. 3.45
16	Ipswich - CBD network	M	1.10- Fig. 1



SPEED — SPACING RELATIONSHIPS

Fig. 1.1

(3) Figure 1.1 presents, then, the Speed-Spacing relationship as derived from the many studies detailed in App.1, by the following steps:-

(a) The first, most basic, formula in Traffic Engineering is the one that relates Flow to Speed and Concentration, namely -

$$\text{Flow (vph)} = \text{Speed (kph)} \times \text{Concentration (veh/km)}, \text{ or } - \quad q = v.k \; ; \qquad (1.15)$$

(It should be pointed out that the 'space-mean speed', $\bar{v}_s$ is being used in this formula; while considering the question of traffic flow, it is possible to use time-mean speed $\bar{v}_t$, which is the mean of the instantaneous speeds of vehicles passing a point on the road in a period of time, or to use the space-mean speed $\bar{v}_s$, which is the mean of the instantaneous speeds of vehicles along a stretch of road. An important advantage of the space-mean speed $\bar{v}_s$ is that it is simply related to the flow q and concentration k by the formula $q = \bar{v}_s.k$. It has already been demonstrated that the space-mean speed has to be used in Eq. 1.15. For example, Ref.1.11, 1.12).

It should also be mentioned here that since the space-mean speed is the mean of the speeds of vehicles along a stretch of road, it represents the Overall Travel Speed, namely the total distance traversed divided by the total time required, including all traffic delays.

(b) Since Spacing is the reciprocal of Concentration, it follows that -

$$\text{Flow (vph)} = \frac{1,000 \times \text{Speed (kph)}}{\text{Spacing (m/veh)}} \; ; \qquad (1.16)$$

$$\text{or - Spacing (m/veh)} = \frac{1,000 \times \text{Speed (kph)}}{\text{Flow (vph)}} \; ; \qquad (1.17)$$

This Spacing, when based on the hourly volume, is the average Spacing, including the grouping of vehicles into platoons and the distance-gaps between them. It is, thus, the 'macroscopic' spacing on the road, in contrast with a 'microscopic' spacing within a platoon of vehicles.

It is recognized, however, that these rather simple transformations may not adequately represent the most complex mechanism of traffic flow, nor its sensitivity to the intricate variations and interrelationships between the traffic and road parameters, neither can they always be comparable because of the different methods of measurement.

It is of interest to note, therefore, that in spite of all the above limitations and shortcomings, when all the studies are presented in one figure, a clear relationship begins to emerge.

It is apparent, therefore, that the differences between the categories of roads are more prominant than the differences between the various roads within the same category, or between the various methods of measurement.

As can be seen from the various curves in Fig. 1.1, they can be grouped into quite distinct four major categories of roads:-

(1) Freeways and Expressways:- Curves 1-6, with a maximum group-average speed of approximately 85 kph;

(2) Urban major Arterials and Parkways:- Curves 7-9, with a maximum group-average speed of about 50 kph;

(3) Urban Arterials and Roads:- Curves 10-12, with a maximum group-average speed of about 37 kph;

(4) CBD Streets;- Curves 13-16, with a maximum group-average speed of about 30 kph.

This rather important result corroborates the assumption that whatever the method of measurement of the traffic flow characteristics, it can quantitatively only affect the relationship - and even then at marginal levels - while the quality of the various road categories remain quite clear and above the variations.

This conclusion is even more emphasized when considering the different roads which were studied, namely - sections only of Freeways, as opposed to complete CBD roads or networks.

For example, the Tel-Aviv data represents the average daily Speed-Volume relationship for a major CBD street, as measured by the moving-observer method, while the Ipswich data represents a complete network consisting of over 100 unidirectional links in the CBD, where the speed was measured by the moving-observer method at peak periods only and the concentration was determined from a set of aerial photographs taken at the peak periods. Nevertheless, all the CBD road studies, including London, Ipswich, Tel-Aviv, and even a theoretical simulation, conform to the same basic and characteristic pattern.

It may be concluded again, therefore, that the differences between the categories of roads - at high speeds - are more prominent than the differences between the various roads belonging to the same category, or the differences between the methods of measurement.

However, when the speeds decrease, be it on a Freeway or a CBD Street, the Spacing values begin to converge together, signifying that at low speeds, flow characteristics become similar for all categories of

roads; - it is the higher speeds on the other extreme side of the graph that characterize the different road categories.

This extremely important phenomenon is more fully discussed in the following paragraph.

(4) It is of importance to note that most of the studies presented in Fig. 1.1 cover definite ranges of speeds, but never below about 7-10 kph, even for congested CBD streets.

One of the reasons for this is that when unstable flow conditions are encountered at low speeds, where vehicles move and stop alternately, field measurements of speed and flow become difficult. Moreover, even when short-period measurements are considered, the averaging of the data for 1-hr periods tends to smooth-out fluctuations and raise the average speed. (It should be noted that the only exception is the study of Ipswich, where the concentrations - instead of flows or volumes - have been measured directly from aerial photographs, while the speeds have been measured by the moving-observer method at peak hours, thus extending the range of the relationship down to a speed of 3.5 kph only).

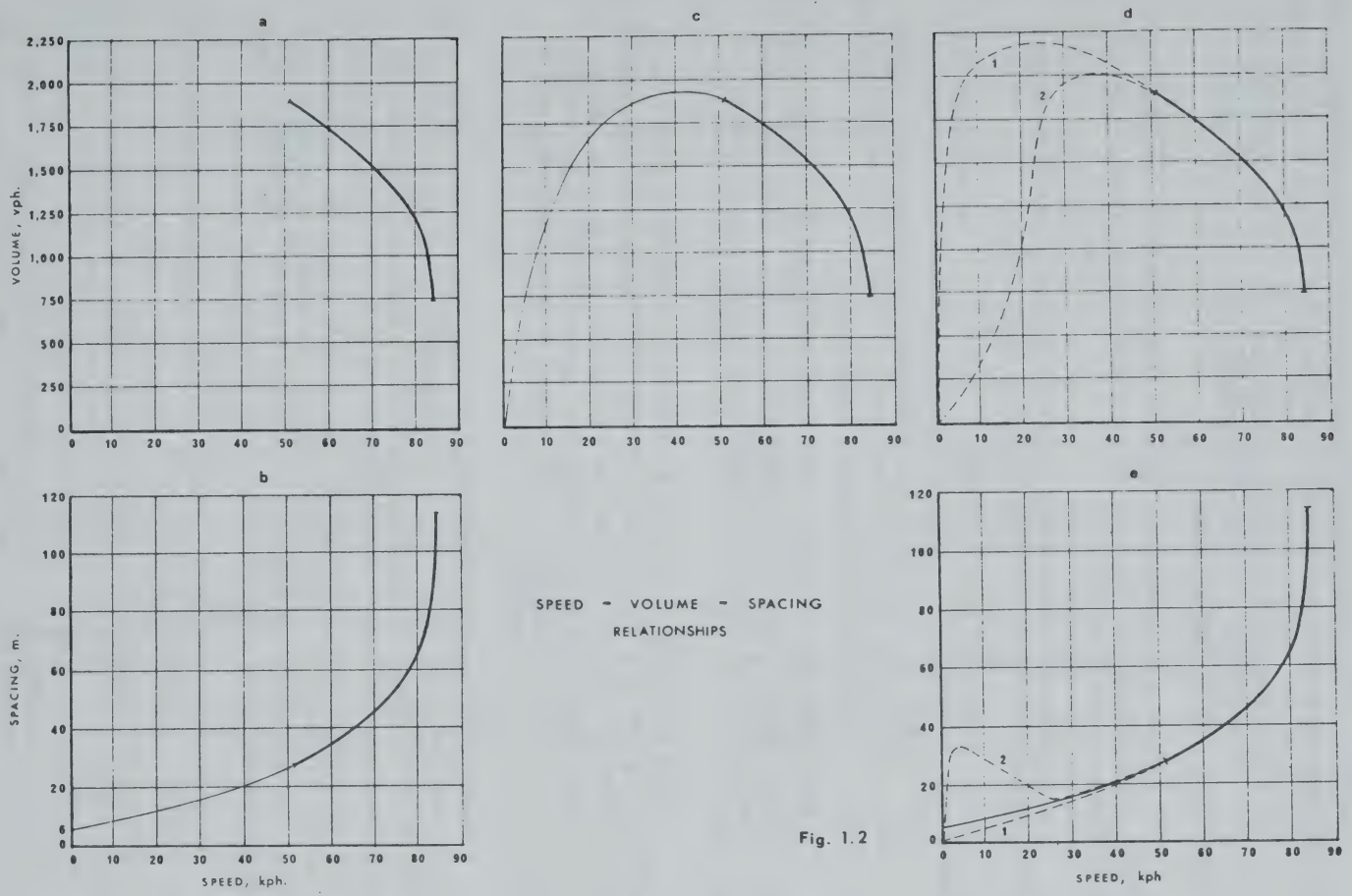
Most, if not all, Speed-Volume relationships are usually presented, therefore, for uninterrupted flow conditions, while the left-hand side of the curves, at low speeds, are usually missing and unknown, or being shown by assumed dotted lines.

In spite of this limitation of Speed-Volume relationship, the presentation of the data in Fig. 1.1 enables to solve this difficulty by a rather simple technique, in the following way:-
It is quite noticeable that all curves in this figure tend to converge to a final spacing of about 6-7 meters at zero speed - which is the minimum possible physical spacing between stationary vehicles in a queue, in passenger-car units (pcu). In other words, notwithstanding the different characteristics of roads at free-flow conditions, they always tend to converge together at congested flows - when speed approaches zero - to a maximum concentration, or minimum spacing.

Based on this trend, the Speed-Volume relationship can thus be supplemented by computation for the congested condition, between the observed measurement and the zero speed.

To explain the procedural steps, an example has been computed, as presented in Fig. 1.2. Curve 'a' presents the original range of observed data for the Santa Anna Freeway, Los Angeles (Ref. 1.8, Fig. 3.37). It covers the Speed-Volume relationship for the speed range from 85 kph down to 50 kph. It is not known from this curve, therefore, how the relationship continues at lower speeds.

The same basic data is presented again in curve 'b', after transforming it into the Speed-Spacing relationship and extrapolating it



SPEED - VOLUME - SPACING
RELATIONSHIPS

Fig. 1.2

down to zero speed = spacing of 6 meters.

Curve 'c' shows again the original Speed-Volume relationship, but now with the addition of the computed section down to zero speed (Appendix 2).

At this stage the question is raised whether the extrapolation of curve 'b' - or curve 'c' - is the only possible one, or some other extrapolation may be better fitting.

To answer this question, curve 'd' shows again the original Speed-Volume relationship, but now with the addition of two extreme possible extrapolations down to zero speed.

Curve 'e', then, presents the transformation of these two Speed-Volume possiblities back into Speed-Spacing relationship.

It can clearly be seen, therefore, that the two assumptions result in unreasonable conclusions, where curve 'e-1' results in spacing zero at zero speed - which is a physical impossibility, while curve 'e-2' results in a sudden increase of spacing at extremely low speeds - which is another absurdity, in contradiction to everyday experience.

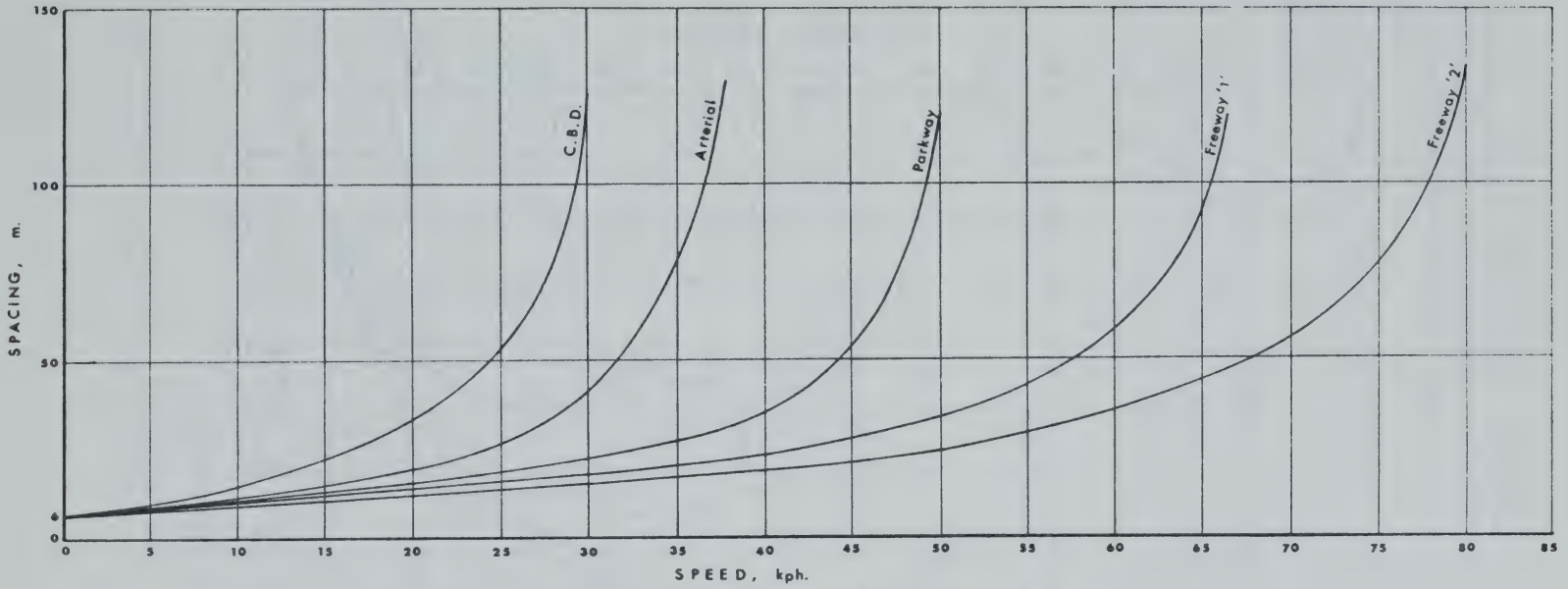
It can safely be concluded, then, that the missing range for any Speed-Volume relationship at the congested, unstable, condition at low speeds, can easily be extrapolated by the use of the Speed-Spacing relationship.

Coming back now to Fig. 1.1, average curves have been drawn, characterizing the four categories of roads, and extended by extrapolation to zero speed = 6 meters spacing, as presented in Fig. 1.3. These four typical curves have then been transformed back into the Speed-Volume relationship, as presented in Fig 1.4, to signify Freeways, Parkways, Urban Arterials, and CBD Streets.

It should be noted that another curve has been added in Fig. 1.4, that for Freeway Type '1'. This was necessiated by the rather different standards of Freeways encountered in various countries. For example, the maximum volume for Freeway Type '2' is over 2,100 vph, signifying a very high standard of Freeways in U.S. towns, while the maximum volume for Freeways in most other cities in the world, covered in this research, is around 1,750 vph only. Freeway Type '1' was added, then by interpolation. (this subject will be further discussed later-on).

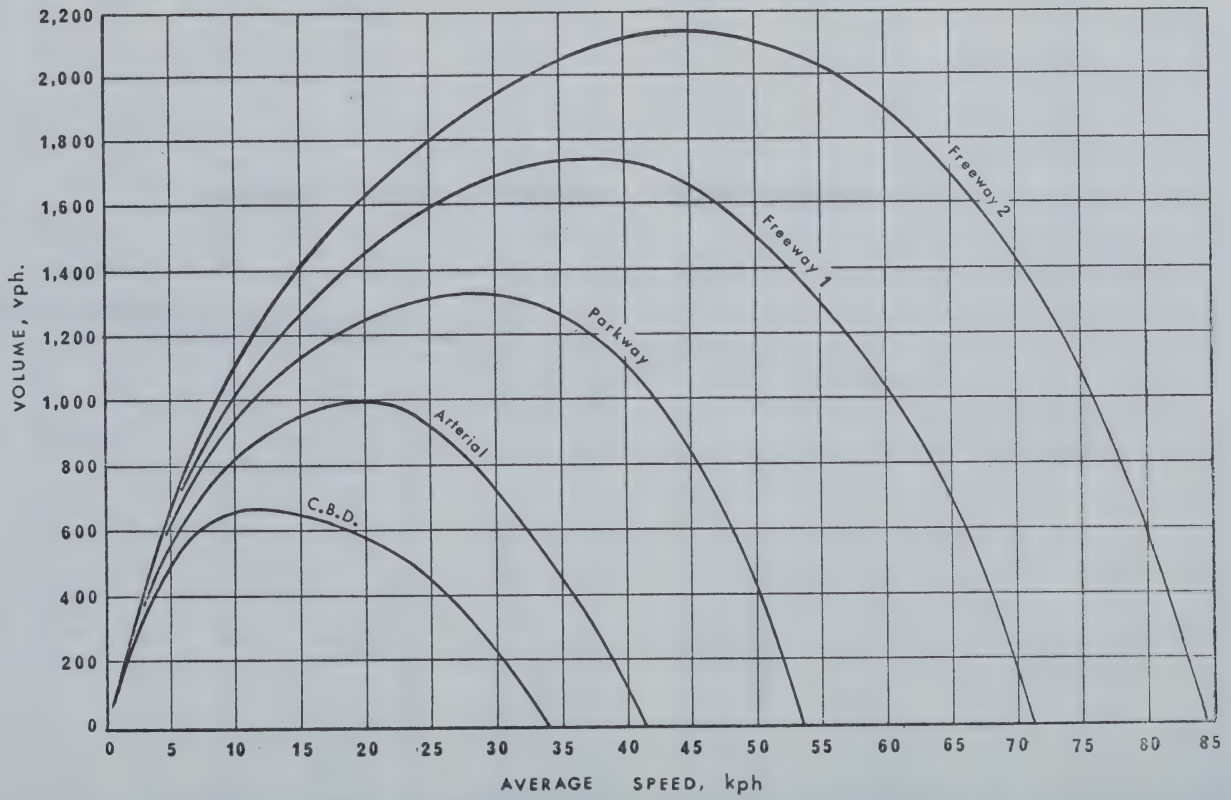
(5) At this stage it becomes alreasy possible to compute the numerical values for the 'C' Factors mentioned in Eq. 1.9.

Fcator 'C' signifies the coefficient by which the spacing at a specific speed on a lane with the most efficient flow conditions should be multiplied in order to find the spacing of any other category of road. In other words, the 'C' Factor signifies the necessary increase in the Dynamic Length of lanes when the standard of a road category is less than the best one. (It



AVERAGE SPEED – SPACING RELATIONSHIPS

Fig. 1.3



AVERAGE SPEED-VOLUME RELATIONSHIP

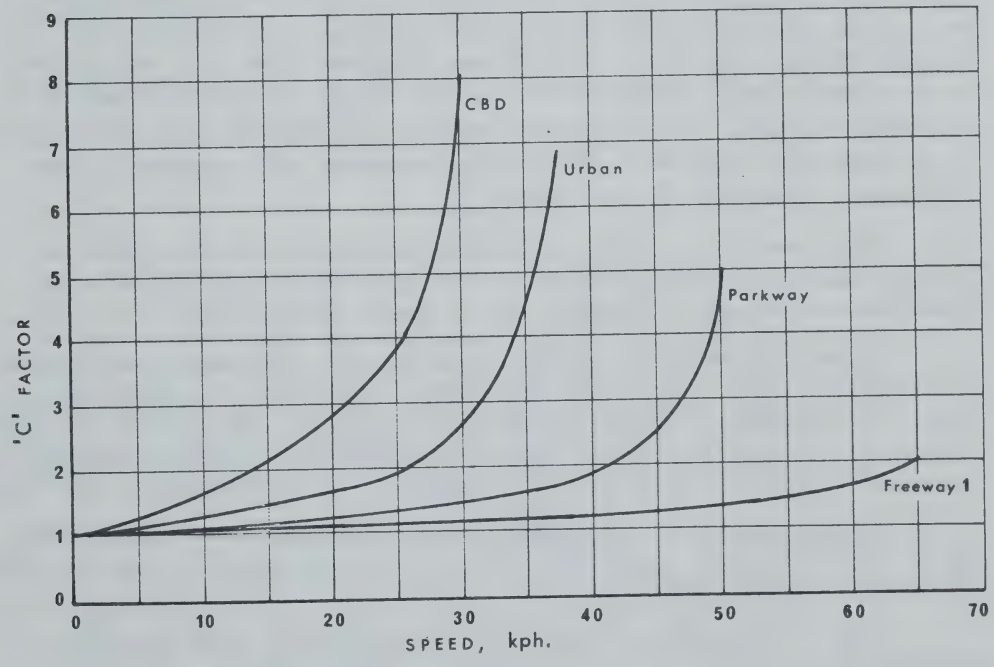
Fig. 1.4

should be noted that since the Kilometrage 'K_p' in Eq. 1.9 is a given constant for a specific city, the independent variable - and the most crucial parameter - in computing the Dynamic Length of lanes is the average speed on the network).

Fig. 1.5 presents the computation of the 'C' Factors at any desired speed for different categories of roads, in comparison with Freeway Type '2' - (Appendix 3).

As can be seen, if an average speed of, let's say, 35 kph is desired for a whole network, Factor 'C' for Freeway Type '1' is 1.2 only; for Parkways it is 1.6; while for Urban Arterials it soars to 4.6. In other words, the length of urban Arterials necessary to achieve and maintain an average speed of 35 kph must be 4.6 times the length of Freeway Type '2' lanes.

It can also be concluded from Fig. 1.5 that no practical length of standard urban road lanes can satisfy a higher desired average speed, for example one of 60 kph.



THE FACTOR 'C'

Fig. 1.5

While this conclusion is true for any extreme case of one caterory of roads only, it is not so while considering a complete network, comprising various categories of roads, or the average speed on such a network; i.e., when wishing to have an average speed of, let's say, 40 kph, this speed can be achieved by various combinations of categories of roads, whether by more Freeways and fewer Arterials, or vice versa.

This flexibility of possibilities enables a quick appraisal of different alternatives of road network planning, as well as a numerical economic analysis of them. This subject will be discussed in Chapter 5, but the principle can be explained here in the following way: - Coming back to Eq. 1.9, namely K/L = v/S, it may be concluded that the total network of roads in a city may be expressed in the form of the average ratio v/S. It should also be noticed that this ratio equals the average Volume K/L per 1-km. of network. Thus, by comparing the ratio K/L (or v/S) for a city against its average speed on the whole network, a numerical value can be defined for the quality of traffic in that city, placing the city at a specific spatial point on a diagram.

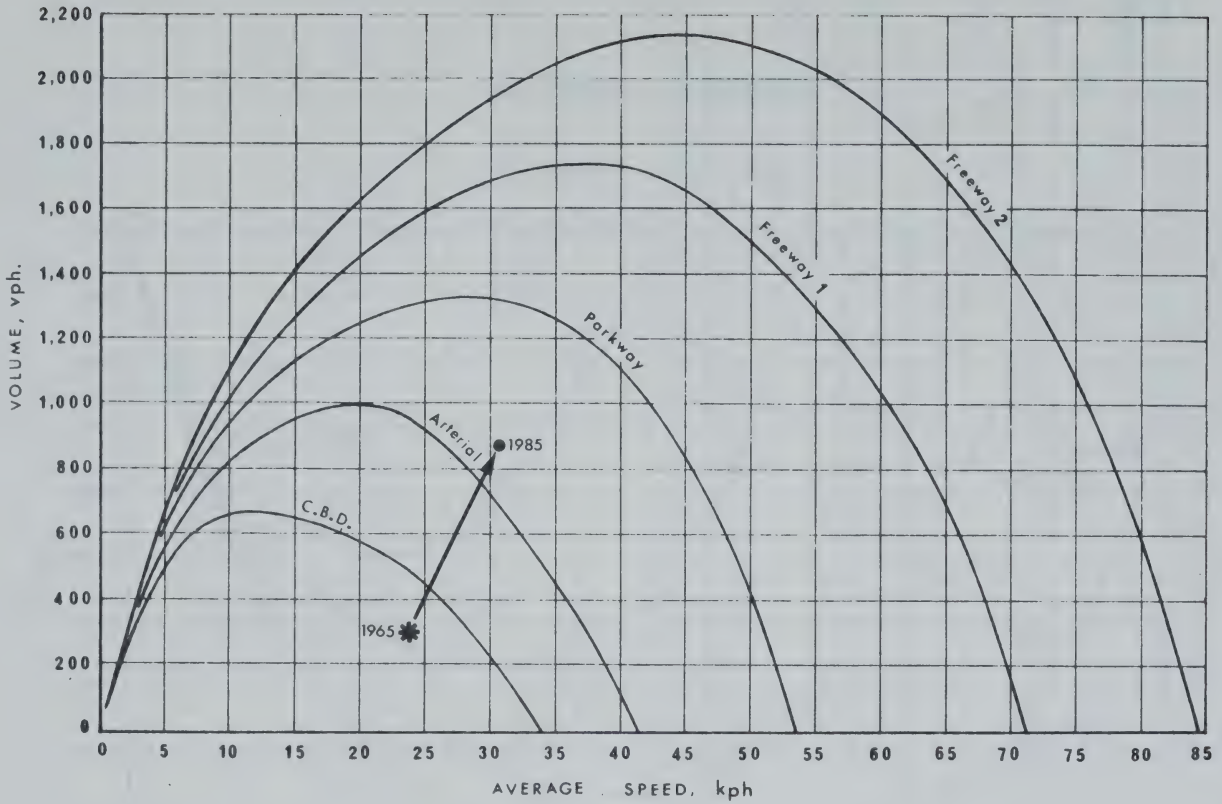
Fig. 1.6 presents only an example of that principle, showing how the traffic quality of a city can be defined not only for a present condition, but also be improved by planning. In this example, of Tel-Aviv, the average speed on the whole network may be raised from 24.8 kph in 1965 to 30.3 kph in 1985, by the addition of just 68 km. of Freeways and 66 km. of urban Arterials, and this despite the fact that the total daily Kilometrage of an urban area with about one million inhabitants will increase by over five times during that 20-year period.

This addition of roads, of various categories, will also raise the average category of the total network from somewhat above that of a low CBD network definition in 1965 to that of nearly Arterial network in 1985.

It can also be shown that two cities can have the same road category classification, while one of them will have a higher average speed than the other:- it depends, of course, on the ratio of v/s for that city or, in other words, on the average 'Volume Density' for that city. ('Volume Density' being the ratio between the total daily Kilometrage to the total length of free lanes).

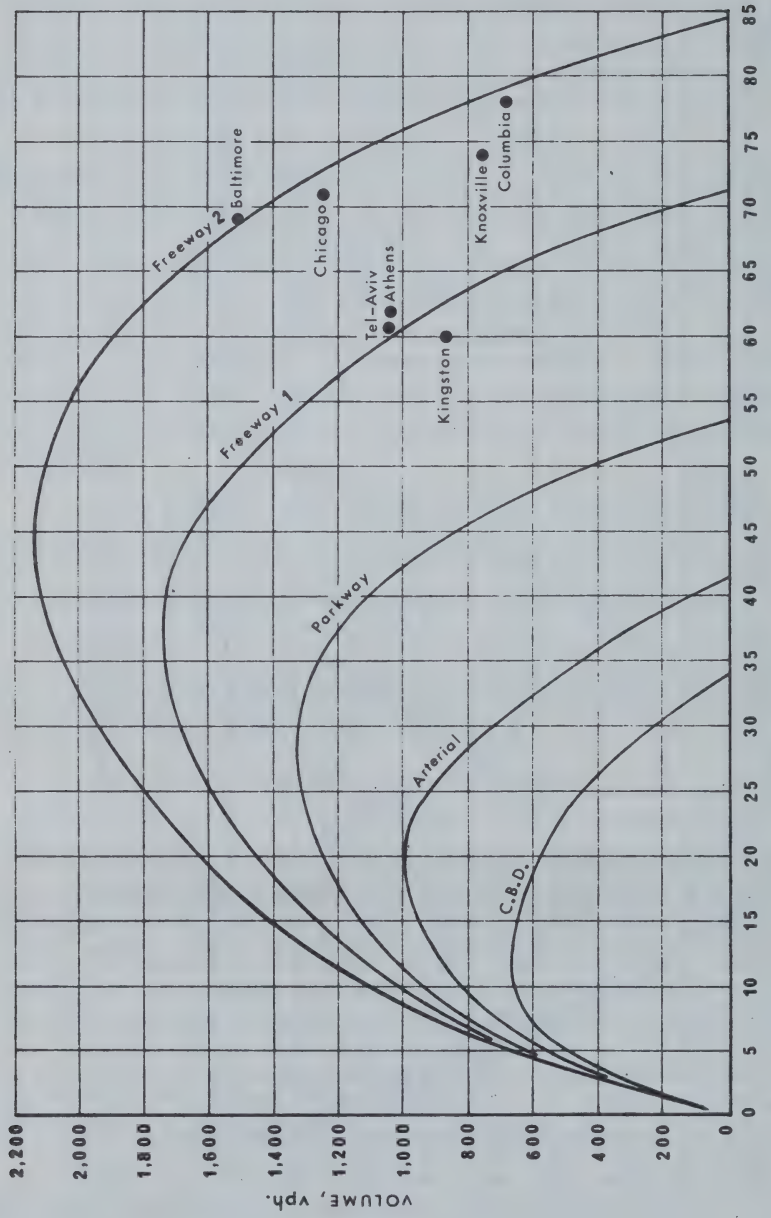
In conclusion, the ability to define quantitatively the traffic quality for a whole city opens many possiblities for a rapid appraisal and evaluation of various planning assumptions and alternatives.

Fig. 1.7 presents the same basic categories of roads as in Fig. 1.6 but now with examples of specific networks of Freeways in some cities covered by this research. Considering the two Freeway categories, it seems now quite natural why the Freeways of four U.S. towns, namely those of Baltimore, Chicago, Knoxville and Columbia, are situated along the curve of Freeway Type '2', signifying a high planning standard, while the Freeways



TRAFFIC CATEGORY OF A CITY

Fig. 1.6



THE FREEWAY CATEGORIES

Fig. 1.7

of three other towns, from other parts of the world, namely those of Athens, Kingston-upon-Hull and Tel-Aviv, are situated along the curve of Freeway Type '1', thus signifying a lower standard then is being used in the U.S.A.

It is alo noteworthy that while the average speed may be different for each separate network (depending on its 'Volume Density') its characteristic category is clearly defined on the specific curve.

This second example shows again how complex traffic data of different towns and cities may be graphically presented - and interpreted - by a simple but systematic method, with far reaching consequences and practical applications.

In summarizing this chapter, the numerical values of the Spacing 'S' and Factor 'C' have been derived, as well as the four categories of roads, or networks, have been defined. It should be noted, however, that this chapter is an introductory one in its nature and scope, and that a more thorough discussion of these subjects will be presented in the following chapters.

The second important factor for computing the Dynamic - Length of a road network, according to Eq. 1.14, is the Total Daily Kilometrage 'K_{di}'. This factor will be discussed and computed in the next chapter.

* * *

CHAPTER 2 - THE DAILY KILOMETRAGE 'K'.

1. Introduction.

The basic assumption has been that since traffic in a city is directly related to the activities within an urban area, it can be computed by using a limited number of characteristic parameters. It has been assumed, therefore, that a minimum of three basic parameters only may be adequate for synthesizing the vehicular traffic patterns for a city, within acceptable levels of accuracy, namely its Population, Motorization, and Area.

The comparative analysis presented in this chapter was carried out for 34 towns, from 4 continents, covering a wide range of population and motorization. For base-year data, for example, the range of population is from less then 74,000 and up to over 8.8 million, and the range of motorization is from less then 1 passenger car per 100 people and up to over 40.

The methodology was to study the available data, analyze the interaction between the parameters, and formulate the best empirical relationships that may explain the traffic patterns in the study areas. The relationships would then have to be tested by synthesizing the expected values and compare them with the given ones.

The decisive relationships are those analyzed for base-year data, since the comparison is then made with the measured actual conditions. However, and with the purpose of trying to develope procedures that may be useful in a general way, including their ability to forecast the traffic patterns for a future date, the comparative analysis also includes projected conditions, as well as the recommended road networks.

A practical comparative analysis depends wholly on the available data presented in the published reports of the comprehensive transportation studies. Therefore, the author of this research had carefully and thoroughly read more than seventy such reports, out of which 34 were finally selected for inclusion in the analysis. The reports that were excluded were either Regional Studies, covering extensive non-urbanized areas, or reports that did not present the minimum amount of data required for the analysis. The following list, in alphabetical order, names a few of such studies, that were excluded:-

Calcuta (India); Clovis (New Mexico); Colwyn Bay, Conway and Llandudno (Wales); Hobart (Tasmania); Hong Kong; Kingston (Jamaica); Leicester (UK); Los Angeles (USA); Mayaguez (Poerto-Rico); Merseyside (UK); O.K.I. - Ohio-Kentucky-Indiana (USA); Pen Jersey (USA), San Juan (Poerto Rico); Sao Paulo (Brazil); Sarnia (Canada); Slough (UK); Southeastern Virginia (USA); South East Lancashire and North East Chesire - SELNEC (UK); Washington-New York-Boston Megalopolis (USA); Wellington (New Zealand); Yuma (USA).

The 34 studies which were finally selected for analysis are detailed in the following Tables:

Table 2.1 - General Information;
Table 2.2 - Trip Information;
Table 2.3 - Network and Kilometrage Information.
List is Detailed in Appendix 4.

At this stage, however, a few remarks about the studies themselves are in order, since any quick comparison between them immediately raises several problems. These problems result not only from the lack of Internationally recognized standards for the presentation of the results, but also from the abundance of the various techniques and procedures preferred by the responsible agancies for carrying out the surveys, processing the data, projecting the crucial parameters into a target-year, and planning the Transportation Plan. Following are a few examples of the problems that may be encountered:

(1) The Study Area: As yet there is no approved procedure for the explicit definition of the area that should be included in the transportation study. Consequently, the area may vary within a wide range, covering wide empty areas around the urban core on one hand, or cutting the central city from its satellite towns on the other hand.

For instance, the area defined for Bombay (India), with a population of over 4.3 million, was 850 sq.km., while for Knoxville (USA), with a population of only 242 thousand, the area defined was 1,360 sq.km. It may be concluded, therefore, that the size of the study area is affected not only by the definition of the existing urban area or by the surrounding area which is expected to be urban in the target-year, but also - and apparently even more so - by the level of motorization, which determines the 'Influence Area' around the central city for its daily commuters.

It is quite clear, therefore, that the size of the area defined for a transportation study is of a prime importance, since it may affect all the surveys' results. For example, changing the area for the same city will immediately change the ratio between Internal and External trips, as well as many other such trip factors.

(2) Types of Vehicles: In most studies passenger-cars are recognized as a separate group; but in some studies the passenger-cars and motor-cycles are grouped together (such as in Birmingham), or part of the commercial vehicles are added to the passenger car group (such as in Copenhagen), thus averaging two different travel behaviours.

(3) Inter-Zonal and Intra-Zonal Trips: The number of trips in a study area are usually broken down into two major groups:- Inter-Zonal and Intra-Zonal; namely, those trips which transfer between pairs of zones, and those that travel within the internal area of a traffic zone.

Table 2.1

GENERAL INFORMATION

No.	Town	Country	Year	Population	Pass. Cars	Motorization (Pass. Cars)	Comm. Veh.	Area, Sq. Km
1	Adelaide	Australia	1965	723,000	198,800	27.5	-	1,120
	"	"	86	1,159,000	443,000	38.3	-	"
2	Amsterdam	Holland	1960	865,000	56,230	6.4	11,262	170
3	Athens	Greece	1962	1,900,000	39,000	2.1	23,000	448
	"	"	80	2,800,000	270,000	9.6	80,000	"
4	Baltimore	U.S.A.	1962	1,607,980	437,540	27.2	47,938	2,220
	"	"	80	2,161,000	734,270	33.9	-	"
5	Baton Rouge	U.S.A.	1965	245,076	86,116	35.2	9,101	393
	" "	"	85	443,000	176,470	39.8	-	"
6	Belfast	Nor. Ireland	1966	504,620	64,248	12.8	-	127
7	Birmingham	U.K.	1962	2,529,010	388,353	15.4	53,956	970
	"	"	85	2,670,900	820,000	30.7	85,000	"
8	Bombay	India	1961	4,345,000	41,679	1.0	14,000	850
	"	"	81	8,058,000	148,753	1.9	32,000	"
9	Brisbane	Australia	1960	593,668	118,827	20.0	37,334	970
	"	"	81	1,020,800	361,270	35.4	61,530	"
10	Charleston	U.S.A.	1965	235,538	73,360	31.2	-	1,290
	"	"	85	387,020	146,066	37.7	-	"
11	Chattanooga	U.S.A.	1960	241,709	72,965	30.2	13,132	490
	"	"	82	344,528	110,248	32.0	17,600	"
12	Chicago	U.S.A.	1956	5,169,663	1,461,646	28.3	130,000	1,430
	"	"	80	7,802,000	2,828,000	36.2	211,000	"
13	Columbia	U.S.A.	1965	195,973	69,300	35.5	11,500	470
	"	"	85	365,463	150,780	41.3	19,000	"
14	Copenhagen	Denmark	1967	1,707,000	342,950	20.1	47,240	2,756
	"	"	85	2,077,730	915,350	44.2	-	"
15	Dundee	Scotland	1969	205,600	34,177	16.6	-	272
	"	"	2001	226,200	103,408	45.7	-	"
16	Helsinki	Finland	1966	637,393	81,488	12.8	13,030	733
	"	"	80	900,000	262,000	29.0	22,900	"
	"	"	2000	1,100,000	429,000	39.0	38,900	"
17	Kingston	U.K.	1967	344,890	43,183	12.5	9,469	107
	"	"	81	372,500	97,170	26.1	11,319	"
18	Knoxville	U.S.A.	1962	241,810	78,374	32.4	9,575	1,360
	"	"	82	335,714	122,740	36.6	-	"
19	London	U.K.	1961	8,826,620	1,249,453	14.1	190,754	2,450
	"	"	81	9,141,000	2,465,000	27.0	329,000	"
20	Melbourne	Australia	1964	1,951,000	517,000	26.5	91,500	1,500
	"	"	85	3,700,000	1,291,400	35.0	194,000	"
21	Monroe	U.S.A.	1965	96,608	31,678	32.8	-	200
	"	"	85	162,500	80,760	49.7	-	"
22	Orlando	U.S.A.	1965	355,619	137,255	38.6	-	1,400
	"	"	85	834,000	351,000	42.1	-	"
23	Pittsburgh	U.S.A.	1958	1,469,375	395,321	26.9	41,903	1,085
	"	"	80	1,902,185	654,263	34.4	61,700	"
24	Ponce	Puerto Rico	1964	129,780	11,494	8.8	-	60
	"	" "	85	250,000	-	-	-	"
25	Pulaski	U.S.A.	1964	222,652	76,337	34.2	17,200	720
	"	"	90	412,103	175,178	42.5	-	"
26	Rapid City	U.S.A.	1963	73,459	26,680	36.3	-	276
	" "	"	85	130,110	62,550	48.2	-	"
27	Richmond	U.S.A.	1964	417,680	137,688	32.9	-	346
	"	"	80	550,660	204,434	37.1	-	"
28	Rotterdam	Holland	1966	1,060,005	139,000	13.1	(18,200)	645
	"	"	90	1,573,564	422,000	26.8	-	"
29	Sioux Falls	U.S.A.	1963	83,684	29,525	35.3	-	147
	" "	"	85	127,789	61,900	48.5	-	"
30	Tel-Aviv	Israel	1965	817,000	39,643	4.9	13,070	190
	" "	"	85	1,225,000	197,570	16.1	35,563	"
31	Tucson	U.S.A.	1960	244,495	88,215	36.1	14,085	1,580
	"	"	80	680,000	354,000	52.0	49,100	"
32	West Midlands	U.K.	1964	2,529,010	388,353	15.4	53,956	972
	" "	"	81	2,670,900	822,000	30.8	85,000	"
33	Winston Salem	U.S.A.	1965	157,630	55,446	35.2	8,350	400
	" "	"	85	256,169	127,398	49.8	-	"
34	Zurich	Switzerland	1960	700,000	54,300	7.8	-	402

Table 2.2

T R I P S

			Internal				External			
No.	Town	Year	Pass. Cars	Comm. Veh.	Total	Taxi	Pass. Cars	Comm. Veh.	Total	Grand Total
1	Adelaide	1965	-	-	-	-	-	-	-	1,027,500
	"	86	-	-	-	-	-	-	-	2,059,900
2	Amsterdam	1960	430,000	220,000	650,000	-	-	-	150,000	800,000
3	Athens	1962	303,000	127,000	430,000	104,000	-	-	22,300	556,300
	"	80	1,208,574	235,000	1,443,574	310,000	-	-	84,000	1,837,574
4	Baltimore	1962	1,433,356	378,029	1,811,385	103,534	-	-	335,090	2,250,009
	"	80	2,542,166	588,590	3,130,756	-	-	-	455,619	3,586,375
5	Baton Rouge	1965	409,951	81,431	491,382	-	55,677	16,147	71,824	563,206
	" "	85	841,712	153,161	994,873	-	-	-	210,842	1,205,715
6	Belfast	1966	361,432	103,252	464,684	-	79,605	17,460	97,073	561,757
7	Birmingham	1962	1,309,938	341,749	1,651,687	-	-	-	273,280	1,924,967
	"	85	2,654,700	559,900	3,214,600	-	-	-	592,000	3,806,600
8	Bombay	1961	202,000	63,138	265,138	240,708	-	-	7,500	513,346
	"	81	690,790	140,524	831,314	293,882	-	-	40,000	1,165,196
9	Brisbane	1960	344,835	171,712	516,547	-	22,445	5,615	28,060	544,607
	"	81	1,162,000	353,700	1,515,700	-	-	-	94,883	1,610,583
10	Charleston	1965	379,565	58,493	438,058	5,507	20,520	6,014	26,534	470,099
	"	85	785,439	95,093	880,532	-	-	-	65,326	945,858
11	Chattanooga	1960	283,000	64,000	347,000	8,000	50,614	13,894	64,508	419,508
	"	82	440,000	88,000	528,000	-	-	-	141,103	669,103
12	Chicago	1956	4,945,382	827,590	5,772,972	171,478	-	-	-	5,944,450
	"	80	10,193,964	2,467,030	12,660,994	-	-	-	-	12,660,994
13	Columbia	1965	329,892	52,201	382,093	4,944	63,110	13,082	76,192	463,229
	"	85	697,742	87,567	785,309	-	-	-	164,807	950,116
14	Copenhagen	1967	1,445,300	543,700	1,989,000	-	25,700	15,100	40,800	2,029,800
	"	85	3,272,180	742,562	4,014,742	-	-	-	164,123	4,178,865
15	Dundee	1969	151,090	59,183	210,273	-	-	-	17,395	227,668
	"	2001	474,289	73,899	548,188	-	-	-	39,950	588,138
16	Helsinki	1966	219,600	139,200	358,800	36,500	21,700	12,200	33,900	429,200
	"	80	583,900	254,100	838,000	74,100	63,400	16,500	79,900	992,000
	"	2000	1,123,500	434,500	1,558,000	86,200	149,600	28,800	178,400	1,822,600
17	Kingston	1967	226,000	69,100	295,100	-	44,000	17,100	61,100	356,200
	"	81	543,000	90,900	633,900	-	91,000	23,100	114,100	748,000
18	Knoxville	1962	362,887	62,827	425,704	2,495	(45,692)	(15,915)	73,073	489,806
	"	82	577,000	84,000	661,000	-	-	-	164,785	825,785
19	London	1961	3,648,742	1,062,419	4,711,161	183,400	-	-	557,284	5,451,845
	"	81	8,160,000	1,767,000	9,927,000	173,000	-	-	1,220,000	11,320,000
20	Melbourne	1964	1,419,680	518,951	1,938,631	105,904	-	-	85,405	2,129,940
	"	85	6,116,000	1,206,000	7,322,000	-	-	-	187,600	7,509,600
21	Monroe	1965	183,196	40,869	224,065	1,504	21,880	9,544	31,424	256,993
	"	85	406,267	71,250	477,517	-	-	-	96,981	574,498
22	Orlando	1965	594,228	84,231	678,459	5,551	50,865	17,158	68,023	752,033
	"	85	1,410,751	171,401	1,582,152	9,559	-	-	213,755	1,805,466
23	Pittsburgh	1958	1,256,535	229,409	1,485,944	29,102	216,211	91,148	307,359	1,822,405
	"	80	2,251,330	349,450	2,600,780	44,143	-	-	433,000	3,077,923
24	Ponce	1964	-	-	110,449	-	-	-	28,652	139,101
	"	85	-	-	299,666	-	-	-	63,962	363,628
25	Pulaski	1964	432,084	63,555	495,639	7,406	45,807	16,565	71,623	574,668
	"	90	-	-	1,175,586	-	-	-	209,377	1,384,963
26	Rapid City	1963	118,992	16,746	135,738	1,320	11,056	3,916	14,972	152,030
	" "	85	277,678	33,119	310,797	-	-	-	30,471	341,268
27	Richmond	1964	542,489	94,140	636,629	16,150	97,927	24,254	122,181	774,960
	"	80	957,995	137,467	1,095,462	-	-	-	360,157	1,455,619
28	Rotterdam	1966	437,737	106,052	543,789	-	143,431	40,063	183,494	727,283
	"	90	1,393,136	130,496	1,523,632	-	497,033	109,693	606,726	2,130,358
29	Sioux Falls	1963	176,972	25,317	202,289	2,936	19,561	5,322	24,883	230,108
	" "	85	374,329	40,982	415,311	-	-	-	54,703	470,014
30	Tel-Aviv	1965	309,500	118,750	428,250	-	20,274	10,086	30,360	458,610
	" "	85	1,350,000	337,500	1,687,500	-	131,300	28,600	159,900	1,847,400
31	Tucson	1960	331,193	56,920	438,113	2,064	13,660	4,909	18,569	458,746
	"	80	1,373,900	250,000	1,628,900	7,500	45,000	16,000	61,000	1,697,400
32	West Midlands	1964	1,220,000	(234,450)	(1,454,450)	-	173,000	107,300	280,300	1,734,750
	" "	81	-	-	-	-	-	-	-	3,284,700
33	Winston Salem	1965	242,345	42,560	284,905	4,176	65,497	17,877	83,374	372,958
	" "	85	502,632	59,391	562,023	-	-	-	231,033	793,056
34	Zurich	1960	-	-	450,000	-	-	-	49,200	529,200

Table 2.3

THE ROAD NETWORKS

No.	Town	Year	Total Kmt. (000)	Freeways				Expressways			Arterials			Locals			Average v	Remarks
				Length	Lane Length	Kmt. (000)	v	Length	Kmt. (000)	v	Length	Kmt. (000)	v	Length	Kmt. (000)	v		
1	Adelaide	1965	6,625.0	-	-	-	-	-	-	-	755	5,170.0	-	-	-	-	-	
	"	86	15,335.0	98	682	4,020.0		79	1,175.0	-	855	7,000.0	-	-	3,140.0	-	-	
2	Amsterdam	1960	2,000.0	1	4	30.0	100.0	-	-	-	500	1,700.0	15.0	700	270.0	10.0	15.6	City only. Kmt. is estimated.
3	Athens	1962	3,100.0	-	-	-	-	-	-	-	-	-	-	-	-	-	39.5	
	"	80	12,000.0	96	558	5,800.0	65.0	-	-	-	458	5,450.0	36.0	-	750.0	-	50.0	
4	Baltimore	80	41,000.0	250	1,450	21,900.0	73.5	(-)	(-)	(-)	398	(19,100.0)	(45.4)	-	-	-	(56.5)	Kmt.: A & E. No Locals.
5	Baton Rouge	1965	3,025.0	-	-	100.0	62.7	-	-	-	-	2,570.0	46.5	-	355.0	22.9	41.8	
	" "	85	8,500.0	61	-	1,970.0	72.2	-	-	-	171	(6,530.0	(46.0)	72	(-)	(-)	50.2	Kmt.: A & L.
6	Belfast	1966	2,607.5	-	-	26.7	59.0	-	-	-	(357)	2,518.3	31.9	640	62.5	30.6	32.4	Kmt. 16 hours. Length: F & A.
7	Birmingham	1962	10,700.0	-	-	-	-	-	-	-	920	(10,700.0)	-	394	(-)	-	-	Kmt.: A & L. Incl. M/c.
	"	85	22,600.0	-	-	-	-	-	-	-	-	(22,600.0)	-	-	-	-	-	Kmt.: A & L. Incl. M/c.
8	Bombay	81	10,364.0	67	395	3,310.0	55.3	-	-	-	246	6,440.0	34.2	670	614.0	22.4	37.8	
9	Brisbane	81	14,860.0	155	-	7,570.0	74.0	-	-	-	530	(7,290.0)	40.0	279	-	30.0	(53.5)	Kmt.: A & L.
10	Charleston	85	-	(115)	-	-	-	(-)	-	-	(515)	-	-	-	-	-	-	No Kmt. Length: F & E, A & L.
11	Chattanooga	82	5,437.0	36	-	1,930.0	-	-	-	-	(550)	3,220.0	-	(-)	287.0	-	-	Length: A & L.
12	Chicago	80	108,700.0	340	4,450	55,400.0	75.0	-	-	-	4,500	53,300.0	48.0	15,700	-	-	54.5	Kmt.: Internal only. No Locals.
13	Columbia	85	5,520.0	(142)	(595)	(4,050.0)	(82.5)	(-)	(-)	(-)	283	(2,570.0)	(48.0)	(-)	(-)	(-)	(64.5)	Kmt. and Length: F & E, A & L.
14	Copenhagen	1967	16,038.0	44	-	1,228.0	97.7	-	-	-	1,480	12,951.0	44.2	545	1,859.0	38.8	45.4	
	"	85	39,791.0	374	-	(25,600.0)	(85.0)	(-)	(-)	(-)	1,765	13,800.0	47.0	545	391.0	(30.0)	65.5	Kmt.: F & E.
16	Helsinki	1966	1,699.0	24	-	260.0	-	5	110.0	-	586	1,377.0	-	(1,167)	152.0	-	-	
	"	2000	21,649.0	175	1,668	9,779.0	-	139	5,010.0	-	536	5,529.0	-	(-)	1,331.0	-	40.0	
17	Kingston	1967	1,482.0	-	-	-	-	-	-	-	96	1,045.0	38.6	136	437.0	38.4	38.6	
	"	81	3,503.0	17	85	728.0	63.0	-	-	-	111	1,945.0	42.4	147	830.0	39.4	44.6	
18	Knoxville	82	8,700.0	104	416	3,120.0	74.3	-	-	-	244	4,750.0	56.3	345	830.0	36.0	58.3	
19	London	1961	39,200.0	(444)	-	(11,400.0)	-	-	-	-	1,435	19,850.0	-	1,228	7,950.0	-	34.6	Not Freeways.
	"	81	101,550.0	542	3,745	55,200.0	65.0	-	-	-	-	(46,450.0)	36.0	(-)	(-)	(-)	47.2	Kmt.: A & L
20	Melbourne	1964	14,800.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
	"	85	72,450.0	495	-	37,000.0	67.0	-	-	-	3,060	27,400.0	47.0	-	8,050.0	30.0	51.5	
21	Monroe	1965	1,150.2	-	-	42.7	80.5	-	-	-	-	960.0	38.0	-	147.5	20.8	37.4	
	"	85	2,480.0	18	-	430.0	75.7	-	-	-	213	(2,030.0)	(43.0)	59	(-)	(-)	48.5	Kmt.: A & L.
22	Orlando	85	13,650.0	(227)	-	(5,420.0)	(81.2)	(-)	(-)	(-)	864	10,900.0	55.2	-	1,340.0	23.1	55.9	Kmt.: F & E.
23	Pittsburgh	1958	13,800.0	31	-	-	-	-	-	-	1,750	12,250.0	35.0	-	4,130.0	-	-	
	"	80	24,200.0	338	-	-	-	-	-	-	-	13,250.0	39.0	-	-	-	-	
24	Ponce	85	1,472.0	(30)	-	(350.0)	(74.4)	(-)	(-)	(-)	83	1,122.0	35.9	-	-	-	(41.0)	Kmt. & Length: F & E. No Locals.
25	Pulaski	90	9,970.0	(183)	-	(6,220.0)	(80.5)	(-)	(-)	(-)	410	(3,750.0)	48.6	145	(-)	(-)	63.2	Kmt.: F & E, A & L.
26	Rapid City	85	1,852.0	27	-	459.0	82.3	-	-	-	193	1,393.0	43.2	-	-	-	(49.0)	No Locals.
27	Richmond	80	16,320.0	(312)	-	(9,360.0)	(84.2)	(-)	(-)	(-)	(715)	(6,960.0)	(48.2)	(-)	(-)	(-)	(63.8)	Kmt. and Length: F & E, A & L.
28	Rotterdam	1966																
	"	90																
29	Sioux Falls	85	2,520.0	62	-	910.0	82.5	-	-	-	462	1,610.0	48.4	-	-	-	(57.0)	No Locals.
30	Tel-Aviv	1965	1,874.0	-	-	-	-	-	-	-	172	1,433.0	33.0	121	441.0	21.0	26.0	
	" "	85	9,891.0	68	326	3,422.0	84.0	-	-	-	243	4,767.0	36.0	(125)	1,702.0	20.0	38.3	Local Length: Assumed as Base-Year.
31	Tucson	80	13,400.0	116	-	5,150.0	81.0	515	980.0	66.5	935	6,350.0	50.6	582	1,000.0	37.8	58.5	
32	West Midlands	1964	10,100.0	-	-	-	-	-	-	-	920	-	-	395	-	-	37.0	
	" "	81	22,500.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
33	Winston Salem	85	5,280.0	(112)	-	(3,060.0)	(82.2)	(-)	(-)	(-)	(211)	(2,220.0)	(48.7)	(-)	(-)	(-)	(63.8)	Kmt. and Length: F & E, A & L.
34	Zurich	1960	3,267.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	

The total trips in the study area include, therefore, the Inter plus Intra trips, while the trips that are assigned to the road networks usually include only the inter-zonal trips. However, not only may the ratio between the inter and intra trips vary to a great extent from town to town (depending heavily on the size of the traffic zones, or the proportions between vehicle types), but in many reports no such distinction is made at all, and the reader does not know to which group the trips refer to.

In the few cases where this distinction is fully made, a wide range of values is found. For example, for passenger cars the intra-zonal trips, in percentage from the total number of trips, are: Helsinki - 6.4%; Hobart - 10.2%'; London - 12.1%; and Rapid City - 18.5%.

The rations for commercial vehicles are even more extreme, depending not only on the type of commercial vehicle, but also on the principles of linking together short delivery-trips. For example, in Helsinki the average value for the intra-trips is 10.8%, while in Rotterdam it is 34.4% for light comm.veh. and 22.5% for heavy ones.

Consequently, the total trips and vehicle-kilometrage defined for a study area may vary to a significant extent if they include - or do not include - intra-zonal trips.

(4) Defining the Road Network for Assignment: The network coded for assignments is not the full inventory of roads in the area, but includes only the ones that are considered important or essential for the specific assignment procedure. It usually includes all the Freeways, most of the Arterials and only a small part of the Locals.

However, the final selection depends heavily on the personal choice of the responsible engineer. Therefore, the less roads defined - the more assigned volumes and apparent congestion may result, and vice versa.

Moreover, in some cases Expressways may be defined as a separate category, while in other cases they may be combined with either the Freeways or the Arterials. Thus, the resulting specific assigned vehicle-kilometrage - and speeds - may express different proportions and levels of usage for the same town.

Moreover, it is very seldom that the number of lanes - and free lanes at that - are defined for each category of roads coded for the assignments.

In one case, that of Rotterdam, an additional and unique problem was found:- the definition of the network of Freeways and Expressways had been extended far beyond the study area, to cover extensive parts of Europe. Thus, the network's length, as well as its assigned Kilometrage, were found to be far above those defined for other urban areas of comparable size or characteristics. In this extreme case, therefore, no use could be made with Rotterdam's network data for the comparative analysis.

(5) Lack of Data: While looking at Tables 2.1-2-3, it immediately becomes clear that many studies lack one or more of the relevant parameters that may be considered important for the analysis stages. Since the lack of information is not consistent, such towns were included in the list, with the aim that at least part of their information may be used in the analysis.

By considering all the above factors it may be concluded that any comparative analysis between the many studies may meet with severe difficulties of definitions and results.

It is a challenge, then, to try to uncover the basic relationships, the common denominators, that are stronger than the variations within the above parameters, and that may come to light in spite of such variations.

The following relationships are presented in a sequential order, showing step-by-step how the few basic parameters are interrelated by strong, inherent, forces. At a later stage, after all relationships are developed, a procedure is proposed, by which any comprehensive transportation study may easily be synthesized with sufficient accuracy for a first-approximation evaluation.

It is believed, therefore, that the proposed procedure can be of use for quick and easy appraisal of the transportation needs of a town even before a comprehensive study has been carried out. Moreover, this procedure may usefully be used at each one of the phases of a comprehensive study, for test-purposes, or even after such a study has been carried out, for rapid and easy evaluation of various planning assumptions and alternatives of road networks.

It is recognized, nevertheless, that this research covers a limited number of test-towns and much more research, therefore, is still desirable until the procedure can be perfected to be absolutely conclusive in synthesizing the full transportation data for any town within the current acceptable accuracy standards for a comprehensive study.

At this stage, therefore, the procedure is not proposed to replace a standard comprehensive study, but rather complement it at all stages. It can also be used for quick appraisals of different town structures and road network systems for new towns, at the stage of their planning.

It is believed, however, that this procedure may be further developed, preferably by research-centers with adequate resources (including aerial photography) to become a standard procedure for carrying out comprehensive transportation studies for vehicular traffic. This subject will be fully discussed in the final chapter of this Dissertation.

Following are eight basic relationships for computing - and then synthesizing - the Total Daily Vehicle Kilometrage 'K' for any given town.

2. The Basic Relationships.

A. Daily Trip Rates of Passenger Cars.

(1) Passenger-car Trip Rate, or Trip Factor, is usually defined as the average number of trips per day produced by a car in the study area. However, even at this early stage already several important factors have to be considered:-

(a) Passenger-car trips within the study area are produced by two classes of vehicles; those belonging to the internal population, and those belonging to the external visitors;

(b) Since Internal trips are summarized from the Home-Interview and other such similar internal surveys, it may be assumed that all internal trips by internal cars are accounted for. However, external cars visiting the area are surveyed at the external Cordon and, therefore, only one trip is interviewed, namely the one entering the area or the one leaving the area. All other internal trips by external cars are difficult to survey and, as a rule, are not included in the total number of trips. Moreover, they constitute a small part only of the total number of trips in the study area.

(c) There is a recognized phenomenon of under-reporting of short trips within the study area, since the drivers tend to forget about them.

(d) Should short-trips be linked together, or considered as separate trips? For instance, 10 short deliver-trips along the same street - should they be linked together, or not? The definition of linked trips will affect, therefore, the total number of trips in the study area.

(e) Does the 'total' number of trips include inter plus intra-trips, or only inter trips?

(f) Many internal cars may not have been in use by their drivers on the day/s of interview, whether by being parked, being in garage for repairs, or being outside the study area. How should, then, the Trip Rate be defined - by dividing the total number of internal trips (which has not yet been defined) by the total number of internal cars, or by those cars only that were in use and produced the interviewed trips?

As can be seen, even such simple a factor as the Trip Rate may be affected by complex problems, which have to be considered and defined.

However, since most of the study reports do not define precisely such factors, the only possible solution is to define the passenger-car Trip Rate as the ratio between the total given number of internal passenger-car trips in the study area and the registered number of internal passenger cars. It is recognized that this definition may not be the ideal one, but it

is the best available one, as a common denominator for all the 34 studies.

(2) After the above definition has been chosen, the next question to ask is - with what parameters should the Trip Rate be compared with? Even this question raises several complex problems because it is apparent that conflicting results may be derived from various relationships. In other words, it depends much on the criterion of stratification of the Trip Rates, whether within the same town or by comparing them between different towns. Following is a short summary of several such considerations:-

(a) It is believed that the Trip Rate is decreasing with the increase of motorization, since the more cars owned by people, the less use they have for the cars.

However, this factor may be counterbalanced by other, and more important factors. For example, even if the above statement is assumed to be correct within time-series for the same town, it is certainly not so while comparing it for different towns.

Table 2.4 and Figure 2.1 express this relationship for the study-towns for base-year conditions; namely, between Trip Rates and Motorization. As can be seen, the dispersion is too wide for any significant concludions.

(b) Moreover, even when analyzing the above statement within the same town, an entirely different picture may emerge.

For towns in the United States, for example, it was already concluded (Ref. 2.1.) that:- "The average use of cars owned is generally commensurate with ownership - use is low wherever car ownership is low ...Several factors contribute to the patterns of car use...The zones of low car ownership usually represent low-income populations in high density areas near the center of the city where many destinations are within walking distance and where transit is most convenient. Accordingly, a higher proportion of daily travel is more easily diverted to other modes of travel. Where car ownership is low, most of the cars are used for travel to and from work, and consequently are unavailable for other trips during most of each day".

Consequently, the location of the car within the area may be a more dominate factor than the group of motorization to which it belongs;- the further it is from the center, the more trips it may produce, although belonging to a higher level of motorization group.

(c) Reference 2.1 continues to state:- "The use of successive cars in multi-car families is generally less than the use made of the car owned by a one-car family".

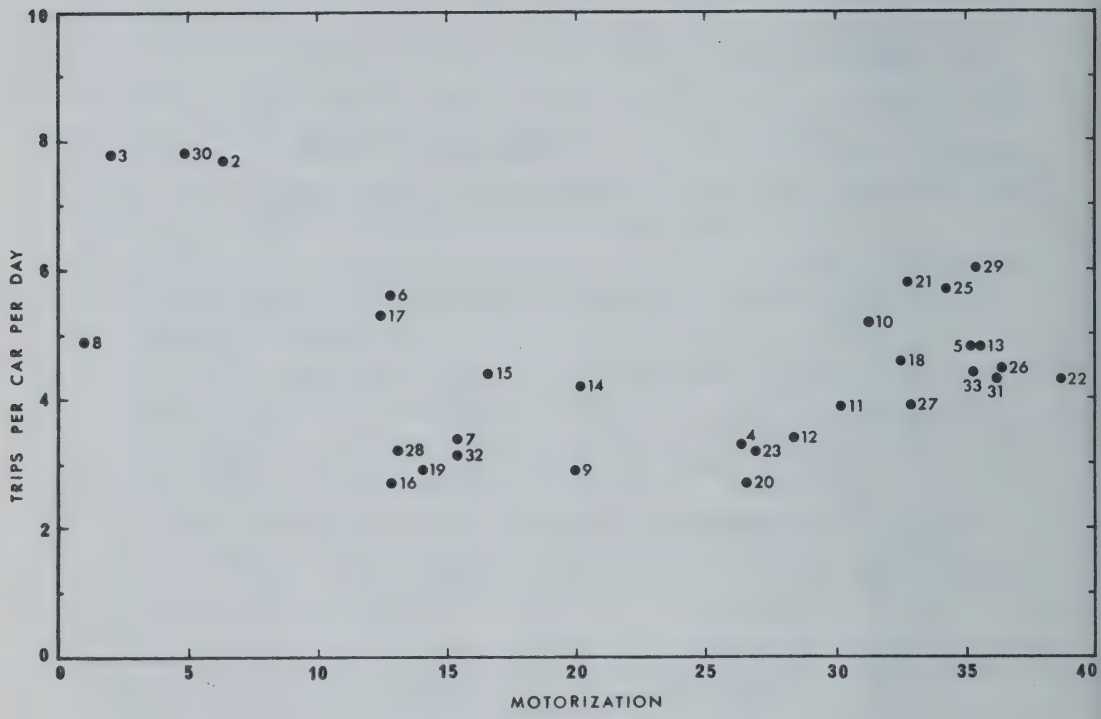
This conclusion, as derived from many researches, seems also to be a logical one, since the more cars owned by a family, the less is the use of each one of them.

Table 2.4

Passenger Car Daily

Trip Rates vs. Motorization

No.	Town	Year	Trip-Rate	Motorization
2	Amsterdam	1960	7.7	6.4
3	Athens	62	7.8	2.1
4	Baltimore	62	3.3	27.2
5	Baton Rough	65	4.8	35.2
6	Belfast	66	5.6	12.8
7	Birmingahm	62	3.4	15.4
8	Bombay	61	4.9	1.0
9	Brisbane	60	2.9	20.0
10	Charleston	65	5.2	31.2
11	Chattanooga	60	3.9	30.2
12	Chicago	56	3.4	28.3
13	Columbia	65	4.8	35.5
14	Copenhagen	67	4.2	20.1
15	Dundee	69	4.4	16.6
16	Helsinki	66	2.7	12.8
17	Kingston	67	5.3	12.5
18	Knoxville	62	4.6	32.4
19	London	61	2.9	14.1
20	Melbourne	64	2.7	26.5
21	Monroe	65	5.8	32.8
22	Orlando	65	4.3	38.6
23	Pittsburgh	58	3.2	26.9
25	Pulaski	64	5.7	34.2
26	Rapid City	63	4.5	36.3
27	Richmond	64	3.9	32.9
28	Rotterdam	66	3.2	13.1
29	Sioux Falls	63	6.0	35.3
30	Tel-Aviv	65	7.8	4.9
31	Tucson	60	4.3	36.1
32	West Midlands	64	3.1	15.4
33	Winston Salem	65	4.4	35.2



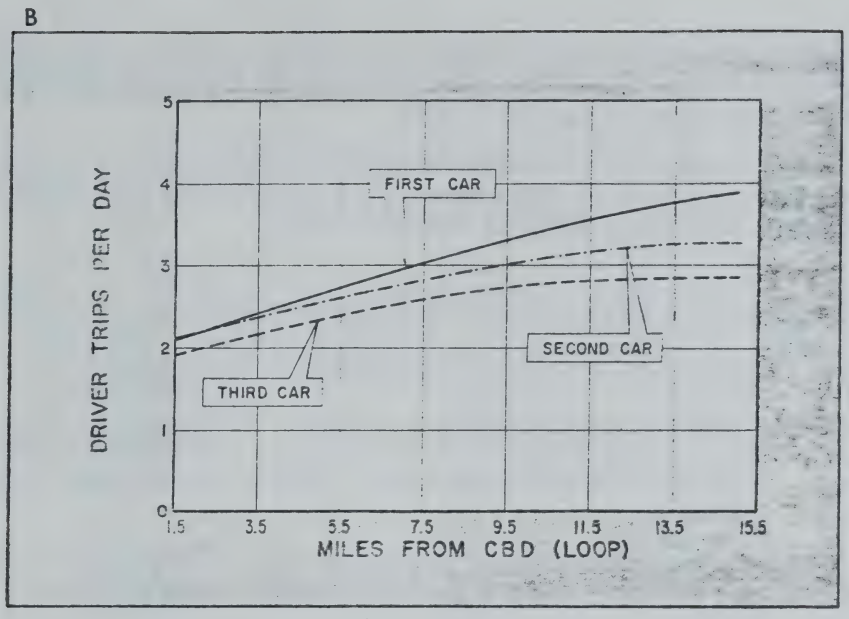
TRIP RATES OF PASSENGER CARS
Base Year

Fig. 2.1

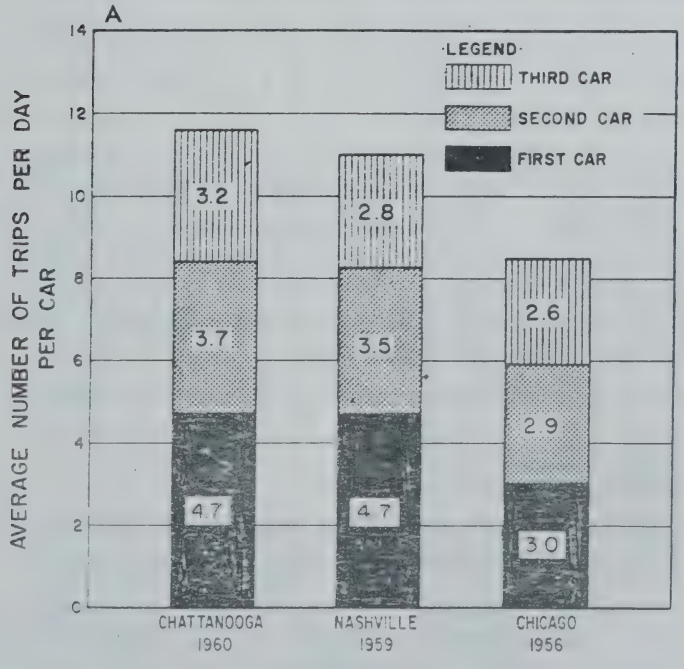
Refering again to Remark (a) above, it may seem again that the higher the motorization level in an area - the higher is the proportion of multi-car families - the less is the overall Trip Rate.

However, even in the seemingly straightforward case of multi-car families, the distance-from-center factor may again counterbalance the overall result for the area.

In the same Ref. 2.1. it continues to say:- "Land-use densities and public transportation affect car use within each city. Their effects are apparent in Fig. 2.2 b', which relates the use of first, second and third cars to distance from Chicago central business district. Families living about 15 miles from the loop make nearly twice as much use of the first car as those who live in or adjacent to it. Use of the second and third cars follows a similar, but less pronounced pattern".



(Figure 36)
USE OF CARS IN MULTI-CAR FAMILIES RELATED TO PLACE GARAGED
CHICAGO, ILLINOIS — 1956



(Figure 35)
USE OF CARS IN MULTI-CAR FAMILIES

Fig. 2.2

What this conclusion does not mention, and is clear from the figure, is that the Trip Rate of the third car far from the center is higher than that of the first car near the center.

In other words, the differential increase and distribution of population and motorization in an urban area may be followed by a prominant increase in the Trip Rate for the whole area.

These few considerations, out of many, show that the total average Trip Rate for an urban area may be affected in different - and often conflicting - ways by the many local characteristics of the area.

Indeed, many relationships have been tried and analyzed in this research between the Trip Rates of the 34 towns and some characteristic parameters, such as population, motorization, density of population, size of the area, and so on.

However, the most significant relationship has been found to be the one between the Trip Rates and the absolute number of passenger-cars.

This phenomenon follows in step of the basic Hypothesis, namely that the vehicles may be recognized as a separate and independent class of 'population' in the area, with its own characteristic and inherent behaviour patterns. Therefore, the more cars in the area, the less is the freedom of each one of them to move freely. Thus, the Trip Rate is expected to decrease, until a minimum level of a specified number of essential trips is being reached.

This conclusion is further strengthened by an additional quotation from Ref. 2.1, which says:- "The average number of trips per car is also greater in small cities than in large cities because of lower densities and less attractive transit service". While it may be questionable whether the same reasons may equally apply to all towns studied in this research, the phenomenon itself is clear; namely, the size of the population, whether of people or vehicles, may affect the Trip Rate.

This subject is further detailed in the following paragraph.

(I) Base-Year Relationship.

Table 2.5 and Figure 2.3 present the relationship between the Trip Rate and the absolute number of passenger cars in the study areas.

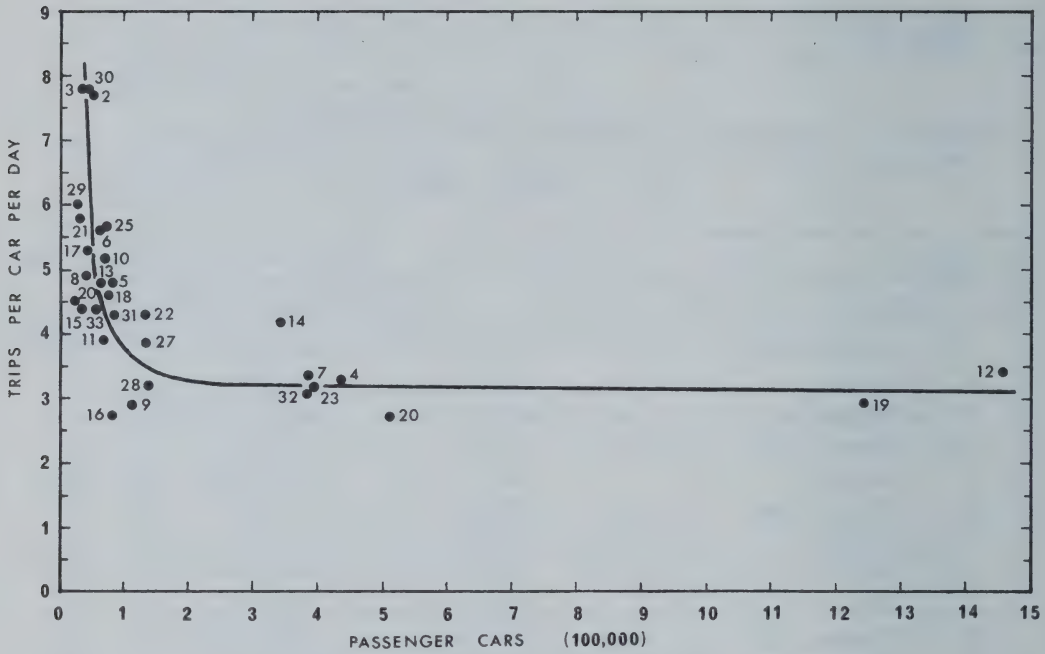
As can be seen, the Trip Rate is very high at a low number of cars, then at the range of a car-population of 30-100,000 it is very sensitive and a sharp drop is observed, until it stabilizes at 3.1 for about 150,000 cars and over.

Table 2.5

Passenger-Car Daily Trip-Rate

Base - Year

No.	Town	Pass. Cars	Total Daily Int. Pass. Car Trips	Trip-Rate
2	Amsterdam	56,230	430,000	7.7
3	Athens	39,000	303,000	7.8
4	Baltimore	437,540	1,433,356	3.3
5	Baton Rouge	86,116	400,951	4.7
6	Belfast	64,248	361,432	5.6
7	Birmingham	388,353	1,309,938	3.4
8	Bombay	41,679	202,000	4.9
9	Brisbane	118,827	344,835	2.9
10	Charleston	73,360	379,565	5.2
11	Chattanooga	72,965	283,000	3.9
12	Chicago	1,461,646	4,945,382	3.4
13	Columbia	69,300	329,892	4.8
14	Copenhagen	342,950	1,445,300	4.2
15	Dundee	34,177	151,090	4.4
16	Helsinki	81,488	219,600	2.7
17	Kingston	43,183	226,000	5.3
18	Knoxville	78,374	362,887	4.6
19	London	1,249,453	3,648,742	2.9
20	Melbourne	517,000	1,419,680	2.7
21	Monroe	31,678	183,196	5.8
22	Orlando	137,255	594,228	4.3
23	Pittsburgh	395,321	1,256,535	3.2
25	Pulaski	76,337	432,084	5.7
26	Rapid City	26,680	118,992	4.5
27	Richmond	137,688	542,489	3.9
28	Rotterdam	139,000	437,737	3.2
29	Sioux Falls	29,525	176,972	6.0
30	Tel Aviv	39,643	309,500	7.8
31	Tucson	88,215	381,193	4.3
32	West Midlands	388,353	1,220,000	3.1
33	Winston Salem	55,446	242,345	4.4



TRIP RATES OF PASSENGER CARS

Base Year

Fig. 2.3

The most plausible explanation for that phenomenon is that when the car population increases, the freedom for an individual car to move freely within its population seems to decrease rapidly. Further stratification of the Trip Rate at the sensitive value of about 50,000 cars, has shown that the dispersion may be explained partially by the level of motorization, where at a low level the Trip Rate is high, and vice versa.

The pattern is consistent for most of the study towns, but for two: Helsinki and Brisbane, for which Trip Rates of 2.7 and 2.9 respectively have been computed. No explanation was given in the studies' reports for such extremely low rates. As will be seen later on, these discrepancies will affect several more relationships, where time and again those two towns diverge greatly from the characteristic curves for all other towns.

(II) Target-Year Relationship.

Forecast of Trip Rates - or any other travel factor - for a target year should be considered with caution, since they are based not on factual data but on assumptions which are selfproving by their nature.

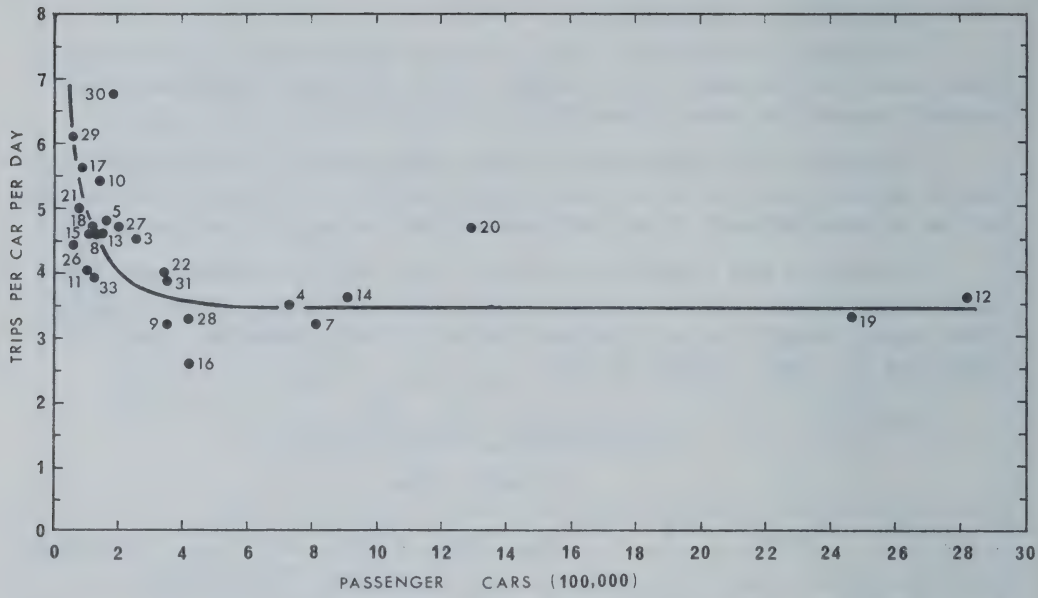
Therefore, all relationships in this Dissertation, for deriving future travel factors, and which are based on projected data, should be considered not as an integral part of the analysis but for comparison purposes only.

Table 2.6 and Figure 2.4 present, then, such a comparison. The same trend is seen again, although with more dispersion, when the Trip Rate decays repidly as the absolute number of cars increases, and stabilizes at a high number of cars.

Table 2.6 Passenger-Car Daily Trip-Rate

Target - Year

No.	Town	Pass. Cars	Total Daily Int. Pass. Car Trips	Trip-Rate
3	Athens	270,000	1,208,574	4.5
4	Baltimore	734,270	2,542,166	3.5
5	Baton Rouge	176,470	841,712	4.8
7	Birmingham	820,000	2,654,700	3.2
8	Bombay	148,753	690,790	4.6
9	Brisbane	361,270	1,162,000	3.2
10	Charleston	146,066	785,439	5.4
11	Chattanooga	110,248	440,000	4.0
12	Chicago	2,828,000	10,193,964	3.6
13	Columbia	150,780	697,742	4.6
14	Copenhagen	915,350	3,272,180	3.6
15	Dundee	103,408	474,289	4.6
16	Helsinki	429,000	1,123,500	2.6
17	Kingston	97,170	543,000	5.6
18	Knoxville	122,740	577,000	4.7
19	London	2,465,000	8,160,000	3.3
20	Melbourne	1,291,400	6,116,000	4.7
21	Monroe	80,760	406,267	5.0
22	Orlando	351,000	1,410,751	4.0
26	Rapid City	62,550	277,678	4.4
27	Richmond	204,434	957,995	4.7
28	Rotterdam	422,000	1,393,136	3.3
29	Sioux Falls	61,900	374,392	6.1
30	Tel-Aviv	197,570	1,350,000	6.8
31	Tucson	354,000	1,378,900	3.9
33	Winston Salem	127,898	502,632	3.9



TRIP RATES OF PASSENGER CARS
Target Year

Fig. 2.4

This figure, however, shows appreciably higher Trip Rates for any given number of cars then for base-year data.

This tendency may be explained by the interaction of two major opposing factors; On the one hand the projected increase in the number of cars tends to decrease the Trip Rate, but on the other hand the projected increase in the number of cars is usually differential, where population and motorization in urban areas grow more rapidly at the fringe than in the center, and consequently tend to raise the Trip Rate. Therefore, and refering again to Fig. 2.2 a'-b', it is apparent that these two conflicting factors produce the same characteristic curve as in Fig. 2.3, but on a higher level of Trip Rates.

There is also an additional factor which may be considered:- While a comprehensive transportation study is usually being conducted in a town only when traffic conditions become quite grave, the recommended plan, on the other hand, envisions better road and traffic conditions, with the aim of alleviating existing traffic difficulties and raising the 'standard of driving' over and above present conditions. Thus, two opposing factors

are at work: - the increase in the number of cars tends to decrease the Trip Rate - because of congestion - while a better network of roads tends to raise the Trip Rate - because it supplies more space and freedom to move.

(3) The comparison between the two curves, for base and target years, may show several more points of interest. For instance, there is an unexplained discrepancy for Melbourne, where a somewhat too-low Trip Rate of 2.7 for base-year jumps to a too-high Trip Rate of 4.7 for the target-year. The same applies for Tel-Aviv, where a too-high Trip Rate seems to have been assumed for the target-year. (Since the author of this Dissertation had been closely related with the Tel-Aviv Study, he checked again the projected Trip Rate and came to the conclusion that the curve in Fig. 2.4 is more representative and that, indeed, the projected Trip Rate had been too high).

In conclusion, the Trip Rates for base-year, as well as for target-year projections, seem to be strongly related to the absolute number of cars registered in the study area.

It may also be concluded that such a comparative analysis may better illuminate the values derived - or projected - in each town, for a better evaluation of their reasonability. In other words, when a comprehensive study is being conducted, and it is found that the computed Trip Rate deviates strongly from the general trend, it would be advisable to check again the basic data. In this way an error - or an unknown and unexpected new factor - may be revealed.

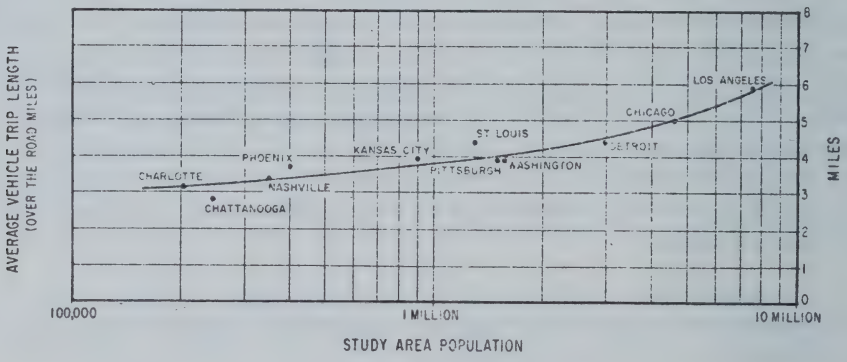
B. Trip Lengths.

(1) The Trip Length may be defined by the average distance travelled between origins and destinations, or by its travel time.

Since most traffic distribution models are based on the time-distribution of trips, it is the Time element that is usually being mentioned in the reports. Thus, distance trip lengths are very seldom treated in the technical literature.

One such exception is the 'Traffic Engineering Handbook' (Ref. 1.2), which has to say the following on this subject;-- "The length of vehicle trips in urban areas are related to the trip purpose and therefore, tend to be as short as possible to meet the traveler's needs. Consequently most urban trips are short averaging, for example, slightly more than three miles in small cities like Reno, and increasing gradually as the urban area grows larger, to more than five miles in cities like Chicago, Detroit, and Pittsburgh". Then the Handbook continues to state:- "The increase in the average individual's vehicular travel in less dense and smaller urban areas is evident". Two tables of distance lengths are then presented in the Handbook.

The second publication which analyzed trip lengths is 'Transportation and Parking for Tomorrow's Cities' (by Wilbur Smith and Associates, Ref. 2.2 The analysis came to the conclusion that trip lengths may be related to the absolute number of population in the urban area. Fig. 2.5 is taken from that publication.



AVERAGE AUTO TRIP LENGTH IN RELATION TO URBAN POPULATION

Fig. 2.5

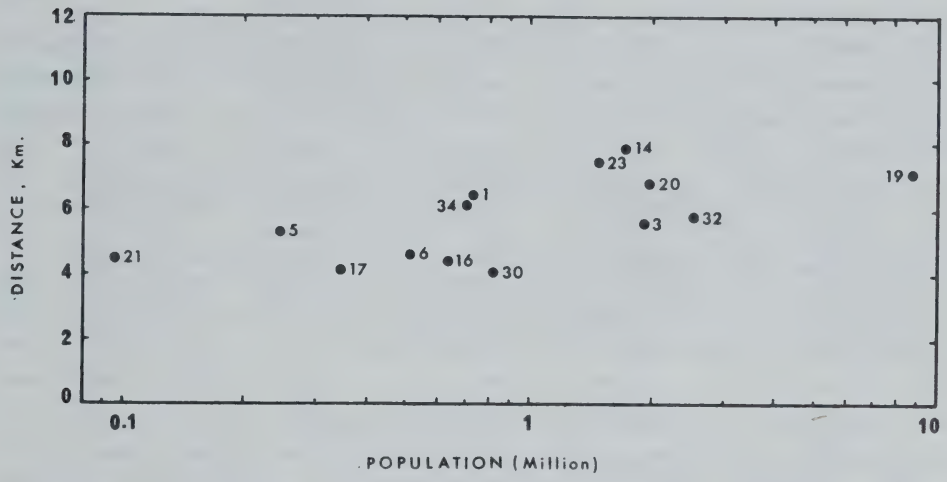
(2) In this research the physical distance trip length has been chosen, with the aim of correlating it with some other physical parameters of the urban area.

The Trip Length has been defined as the result of dividing the Grand total daily Kilometrage by the Grand total daily trips, thus presenting an average trip length for the whole study area. This procedure had to be applied since most of the studies present the total assigned Kilometrage only, for all vehicle types together, and sometimes for the internal plus the external trips put together. Moreover, many studies present travel-times only, without mentioning travel-distance.

Many different relationships, with numerous parameters, have been analyzed in this research with regard to trip lengths. Several previous research-studies have shown a strong correlation between trip-length and a function of population such as, for example, the radius of gyration (Second Moment) of the population about the CBD (Ref. 2.1, page 109), or simply the number of population (Ref. 2.2), as depicted in Fig. 2.5.

However, a similar analysis for the study-towns, as shown in Fig. 2.6, does not present such a strong correlation. In other words, the above

relationship may be true for the United States, but it certainly does not show the same trend for the towns in other parts of the world.



TRIP LENGTH VS. POPULATION

Fig. 2.6

The best relationship which finally has been chosen in this research is that versus the radius of the study area, assuming a circular shape of the area. It is recognized that such an assumption may be too general, but the results, nevertheless, are sufficiently accurate for the purpose of a first-approximation computation, while the radius parameter is certainly a most simple one to derive for any area.

In the following paragraphs such a relationship is presented for base and target years.

(I) Base-Year Relationship

Table 2.7 and Figure 2.7 present the basic data for the relationship for base-year. As can be seen, the two parameters are highly correlated, although the spatial shape of the study-areas varies over a wide range, from circular towns and up to fan-shaped port-towns.

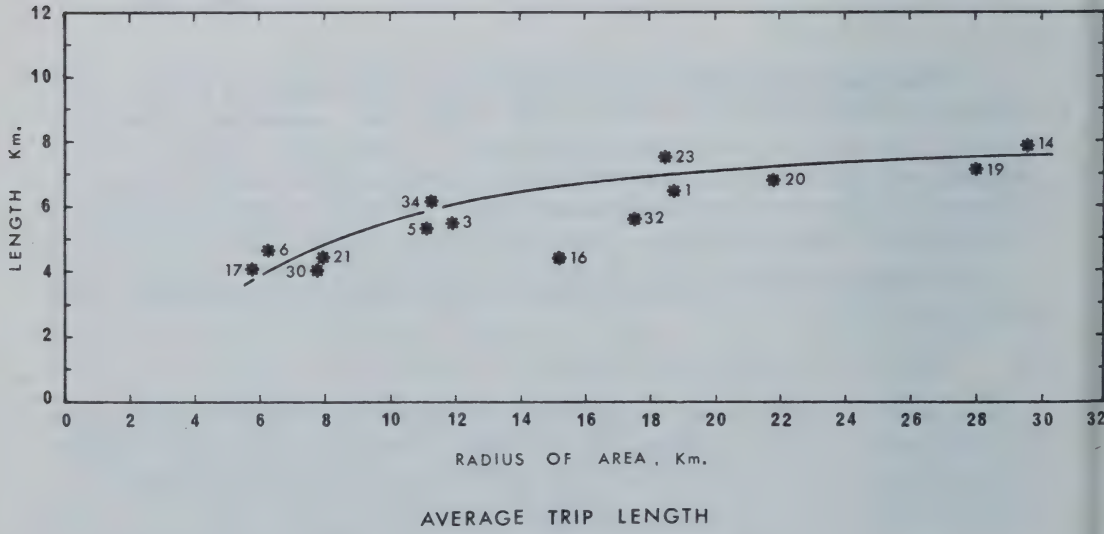
The only town which deviates strongly is Helsinki, which will be discussed in the next paragraph. However, all other towns show that the Trip Length tends to grow gradually with the increase in the radius of the area, up to a saturation level of about 8 km.

Table 2.7

Average Trip - Lengths

Base-Year

No.	Town	Population	Area	Radius	Kilometrage (000)	Trips	Trip Length
1	Adelaide	723,000	1,120	18.8	6,625.0	1,025,500	6.47
3	Athens	1,900,000	448	12.0	3,100.0	556,300	5.57
5	Baton Rouge	245,076	393	11.2	3,025.0	563,206	5.38
6	Belfast	504,620	127	6.4	2,607.5	561,757	4.65
14	Copenhagen	1,707,000	2,756	29.6	16,038.0	2,029,800	7.91
16	Helsinki	637,393	733	15.2	1,899.0	429,200	4.43
17	Kingston	344,890	107	5.8	1,482.0	357,200	4.15
19	London	8,826,620	2,450	28.0	39,200.0	5,451,845	7.18
20	Melbourne	1,951,000	1,500	21.8	14,600.0	2,129,940	6.85
21	Monroe	96,608	200	8.0	1,151.2	256,993	4.48
23	Pittsburgh	1,469,375	1,085	18.5	13,800.0	1,822,405	7.57
30	Tel-Aviv	817,000	190	7.8	1,874.0	458,610	4.09
32	West Midlands	2,529,010	972	17.6	10,100.0	1,734,750	5.83
34	Zurich	700,000	402	11.3	3,267.0	529,000	6.18



AVERAGE TRIP LENGTH

Base Year

Fig. 2.7

(II) Target-Year Relationship.

Table 2.8 and Figure 2.8 present the same relationship for target-years, showing again a similar trend, although with a somewhat higher dispersion.

The most significant difference between base and target years, however, is the projected increase in the trip lengths. The reason for that tendency is that a transportation study area usually covers a wide area, including present parts of empty spaces which will be populated in the future. Thus, it is quite reasonable to expect that the future average trip lengths will increase as the population distribution expands all over the study area, lengthening the distances between population and centers of activities.

Another influencing factor is a Freeway network, which practically every study recommends in the proposed transportation plan, and which tends to lengthen present trip lengths by its operational characteristics. Such a Freeway network may increase the total Kilometrage in the area by as much as 10% .

Two towns only deviate strongly from the relationship, namely Helsinki and Richmond. For Richmond no data is given for base-year and, therefore, it is difficult to acertain the reason for such a deviation. For .

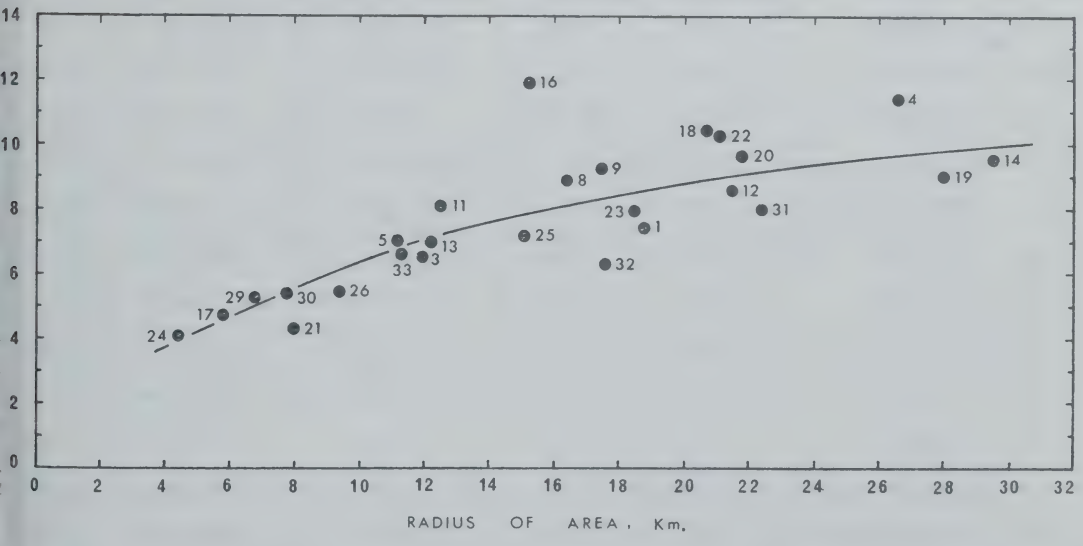


Fig. 2.8

Table 2.8

Average Trip - Lengths

Target - Year

No.	Town	Area	Radius	Kilometrage (ooo)	Trips	Trip Length
1	Adelaide	1,120	18.8	15,335.0	2,059,900	7.45
3	Athens	448	12.0	12,000.0	1,837,574	6.54
4	Baltimore	2,220	26.6	41,000.0	3,586,375	11.40
5	Baton Rouge	393	11.2	8,500.0	1,205,715	7.05
8	Bombay	850	16.4	10,364.0	1,165,196	8.90
9	Brisbane	970	17.5	14,860.0	1,610,583	9.22
11	Chattanooga	490	12.5	5,437.0	669,103	8.13
12	Chicago	1,430	21.3	108,700.0	12,660,994	8.58
13	Columbia	470	12.2	6,620.0	950,116	6.98
14	Copenhagen	2,756	29.6	39,791.0	4,178,865	9.52
16	Helsinki	733	15.2	21,649.0	1,822,600	11.90
17	Kingston	107	5.8	3,503.0	748,000	4.69
18	Knoxville	1,360	20.8	8,700.0	825,785	10.50
19	London	2,450	28.0	101,650.0	11,320,000	8.97
20	Melbourne	1,500	21.8	72,450.0	7,509,600	9.64
21	Monroe	200	8.0	2,460.0	574,498	4.29
22	Orlando	1,400	21.1	18,660.0	1,805,446	10.33
23	Pittsburgh	1,085	18.5	24,200.0	3,033,780	7.98
24	Ponce	60	4.4	1,472.0	363,628	4.05
25	Pulaski	720	15.1	9,970.0	1,384,963	7.20
26	Rapid City	276	9.4	1,852.0	341,268	5.43
29	Sioux Falls	147	6.8	2,520.0	470,014	5.35
30	Tel-Aviv	190	7.8	9,891.0	1,847,400	5.36
31	Tucson	1,580	22.4	13,480.0	1,697,400	7.94
32	West Midlands	972	17.6	22,500.0	3,584,700	6.28
33	Winston Salem	400	11.3	5,280.0	793,056	6.66

Helsinki, however, both base and target data are given. It is of interest to note, therefore, that while the trip length is far below the curve for base year, it is far above the curve for target year. Thus, a discrepancy is revealed, which is contradictory to the general trend.

(3) This example may prove again the importance of a comparative analysis, which may point out an unusual discrepancy that needs an explanation: is it because of a change in the definition of data for the two periods; is it because of an error; or is it because of a specific and strong local factor.

However, the two extreme cases only strengthen the conclusion that the two trip length relationships may be recognized as representative of the base-year factual data, as well as of the current methods for data projections.

C. Commercial Vehicles.

(1) It has already been shown that there is a strong relationship between commercial vehicles - as a percentage of passenger cars - and the level of motorization (For example, Ref. 1.1.). Table 2.9 and Figure 2.9 present this type of relationship for various countries as well as for the study-towns for base-year conditions.

It should be noted that a scatter about the average curve is to be expected, not only as a result of different definitions for a 'commercial vehicle' - by weight, number of axles, by use, by ownership, etc. - but also for various local factors and conditions. For Israel, for example, two such local factors can be mentioned: (a) Israel lacks a developed railway network, thus most goods are transported by trucks; (b) Customs duties for commercial vehicles were for many years much lower than those for passenger cars. Therefore, for a country where such duties for passenger cars add some 200 per cent to the original cost, many commercial vehicles were purchased for strictly private use. These two factors brought about a markedly higher ratio for commercial vehicles in Israel compared with other countries with the same level of motorization.

On the other hand, an error of even 20-30 per cent in estimating the number of commercial vehicles is not critical in most cases, since it will represent errors of a few percent only for the total number of vehicles in a study area. For example, at a motorization level of 10 per cent commercial vehicles constitute about 18 per cent only of the passenger cars, or 15.3% of the total vehicle number. Thus, an error of even $\pm$ 20% in the number of commercial vehicles represents an error of $\pm$3.1% only in the total number of vehicles in the area.

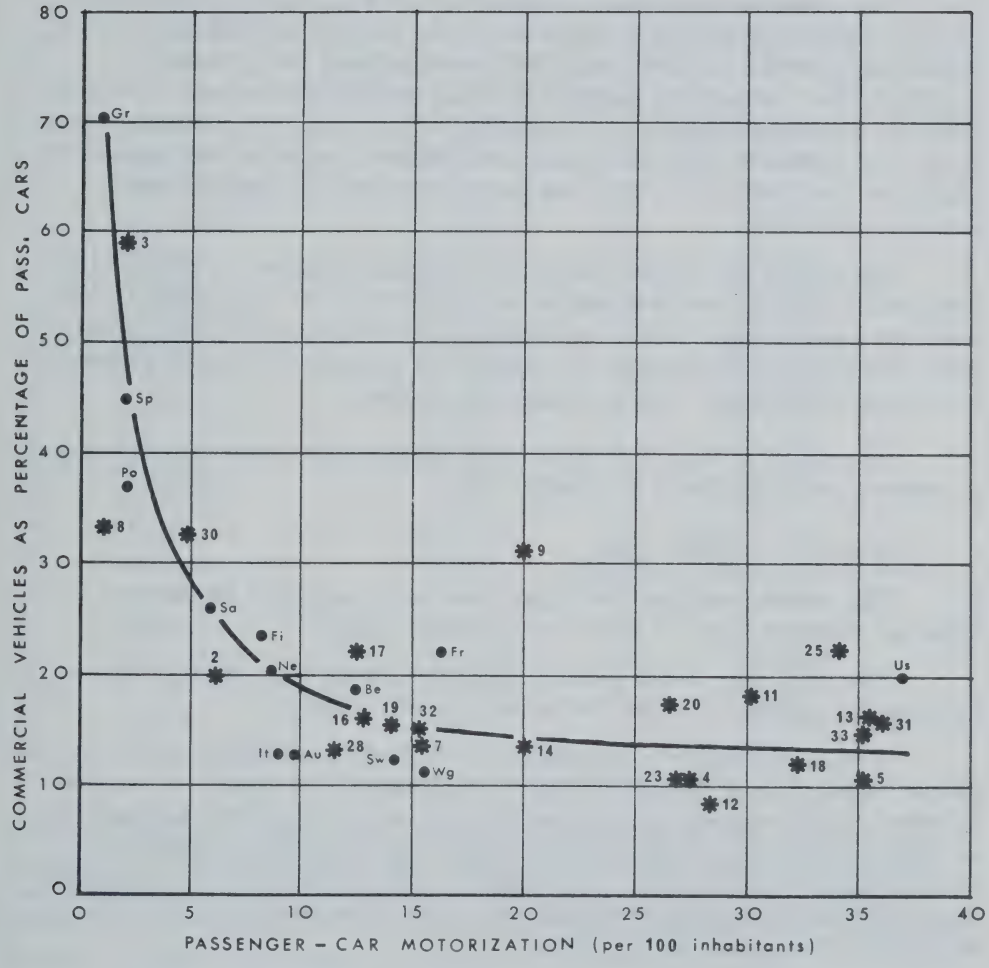
Table 2.9

Commercial Vehicles as Percentage of Passenger Cars

Sources: (a) Countries:- "Automobile Facts & Figures", Automobile Manufacturers Association, USA, 1966 Edition.
(b) Towns:- The Transportation Studies.

No.	Country/Town	Year	Pass. Cars	Motorization	Comm. Veh.	Comm. Veh. as % of Pass. Cars
Au	Austria	64	703,085	9.8	91,469	13
Be	Belgium	64	1,158,483	12.5	213,925	18
Fi	Finland	64	376,000	8.3	87,500	23
Fr	France	64	7,960,000	16.6	1,780,000	22
Gr	Greece	64	81,617	1.0	57,657	71
It	Italy	64	4,631,829	9.0	588,462	13
Ne	Netherlands	64	1,072,500	8.9	218,300	20
Po	Portugal	64	211,000	2.2	78,000	37
Sa	South Africa	64	1,023,000	6.0	268,000	26
Sp	Spain	64	652,297	2.1	296,758	46
Sw	Switzerland	64	830,000	14.3	96,000	12
Wg	West Germany	64	8,689,689	15.6	918,020	11
Us	U.S.A.	64	71,950,198	37.2	14,041,445	20
2	Amsterdam	60	56,230	6.4	11,262	20.0
3	Athens	62	39,000	2.1	23,000	59.0
4	Baltimore	62	437,540	27.2	47,938	11.0
5	Baton Rouge	65	86,116	35.2	9,101	10.6
7	Birmingham	64	388,353	15.4	53,956	13.9 (1)
8	Bombay	61	41,679	1.0	14,000	33.6
9	Brisbane	60	118,827	20.0	37,334	31.4
11	Chattanooga	60	72,965	30.2	13,132	18.0
12	Chicago	56	1,461,646	28.3	130,000	8.9
13	Columbia	65	69,300	35.3	11,500	16.6
14	Copenhagen	67	342,950	20.1	47,240	13.8 (2)
16	Helsinki	66	81,488	12.8	13,030	16.0
17	Kingston	67	43,183	12.5	9,469	22.0
18	Knoxville	62	78,374	32.4	9,575	12.2
19	London	61	1,249,453	14.1	190,754	15.3
20	Melbourne	64	517,000	26.5	91,500	17.7
23	Pittsburgh	58	395,321	26.9	41,903	10.6
25	Pulaski	64	76,337	34,2	17,200	22.6
28	Rotterdam	66	139,000	13.1	(18,200)	13.1
30	Tel-Aviv	65	39,643	4.9	13,070	33.0
31	Tucson	60	88,215	36.1	14,085	16.0
32	West Midlands	64	388,353	15.4	53,956	13.9
33	Winston Salem	65	55,446	35.2	8,350	15.1

Remarks: (1) Passenger cars include Motor-Cycles;
(2) Passenger cars include part of Commercial Vehicles.



COMMERCIAL VEHICLES AS PERCENTAGE OF PASSENGER CARS

Fig. 2.9

Moreover, the commercial vehicle trips are computed, in the next paragraph, by two methods, one of which is independent of the number of commercial vehicles. Thus, the absolute number of this vehicular class is not critical within a wide range.

(2) The relationship itself, as presented in Fig. 2.9, is consistent with the interrelationships found between the various socioeconomic parameters;- while the passenger car is being used for personal activities, the commercial vehicle is being used for communal services. Thus the economic progress of a country brings with it a rapid increase in the acquisition of long-life consumer products, such as refrigerators, television sets, etc., of which passenger cars are a dominant and characteristic part.

Since such an increase follows a Logistic function, with a rapid acceleration at intermediate stages and leveling-off at later stages, and since the commercial vehicle motorization increases at a much slower pace, the relative percentage of commercial vehicles to that of passenger cars should decrease, until a balance is reached.

According to Fig. 2.9 it is to be expected that this saturation level is reached at about 12-15 per cent.

D. Commercial Vehicle Trips.

(1) The commercial vehicle trips have been computed by several different methods, two of which are presented here.

The first one is the most simple and direct one, namely that of relating the number of trips to the number of vehicles.

This relationship is presented in Table 2.10 and Fig. 2.10. As can be seen, it is a straight-forward relationship, showing that with an increase in the number of vehicles there is a corresponding increase in the number of trips, although with a slight decrease in the relative activities of these vehicles. The scatter of the various points around the curve, however, is quite noticeable for each separate case. That is why an additional relationship is proposed.

(2) The second method is that of relating the number of trips to the passenger-car motorization levels, as presented in Tab. 2.11 and Fig. 2.11.

In the light of what has already been said previously, it is not surprising to find such a relationship, especially after looking again at Fig. 2.3 and Fig. 2.9. Moreover, this last relationship can be used as a check on the number of commercial trips already computed by Fig. 2.10.

Another interesting check is by calculating the average Trip Rate of commercial vehicles, by dividing the number of trips by the number of vehicles. This last check merrits an explanation;- The base-year trip

Table 2.10

Commercial Vehicle Trips

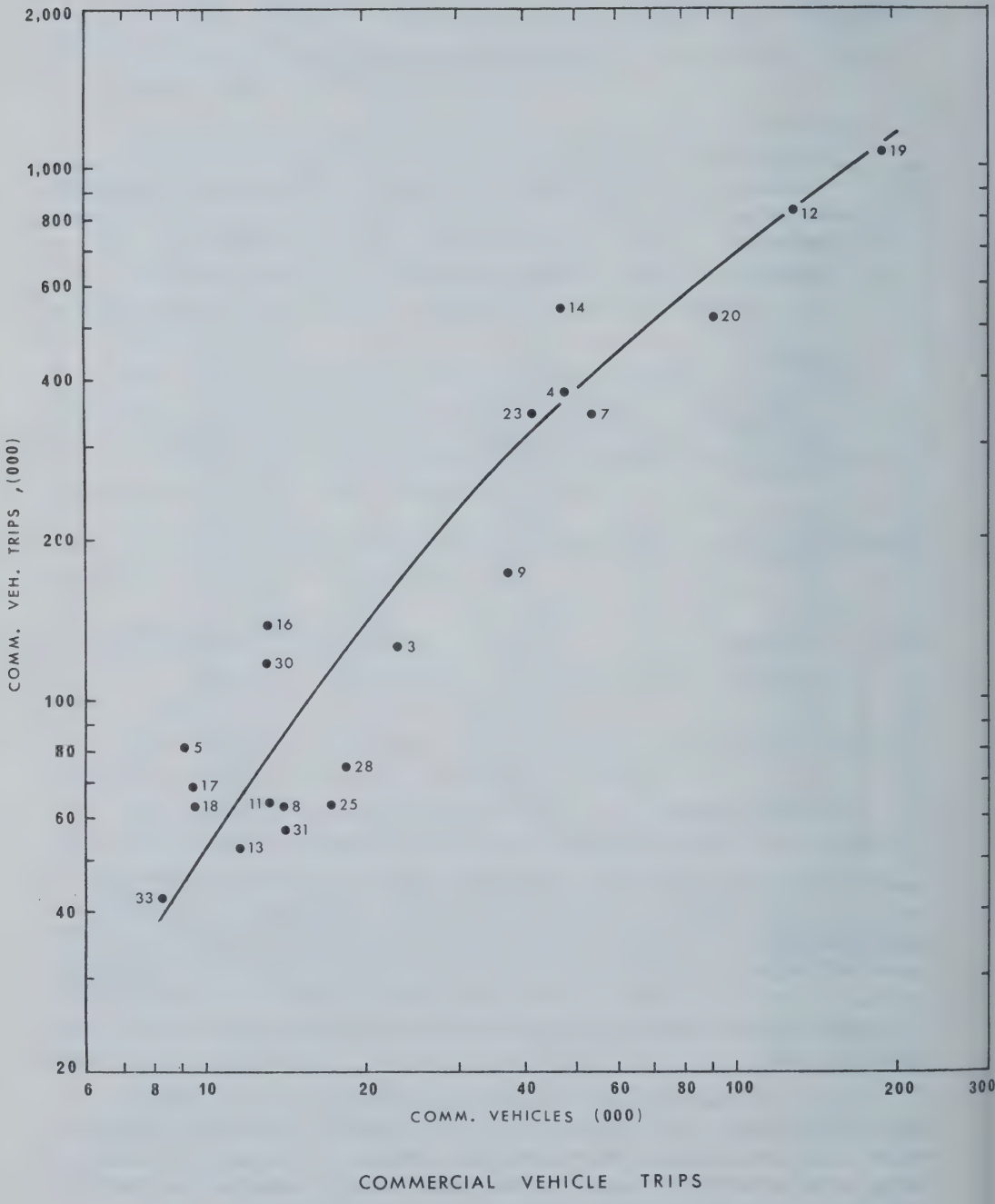
Base - Year

No.	Town	Commercial Veh.	Commercial Veh. Trips
3	Athens	23,000	127,000
4	Baltimore	47,938	378,029
5	Baton Rouge	9,101	81,431
7	Birmingham	53,956	341,749
8	Bombay	14,000	63,138
9	Brisbane	37,334	171,712
11	Chattanooga	13,132	64,000
12	Chicago	130,000	827,590
13	Columbia	11,500	52,201
14	Copenhagen	47,240	543,700
16	Helsinki	13,030	139,200
17	Kingston	9,469	69,100
18	Knoxville	9,575	62,827
19	London	190,754	1,062,419
20	Melbourne	91,500	518,951
23	Pittsburgh	41,903	345,020
25	Pulaski	17,200	63,555
28	Rotterdam	(18,200)	74,721
30	Tel-Aviv	13,070	118,750
31	Tucson	14,085	56,920
33	Winston Salem	8,350	42,560

rates for the study towns were found to vary within a wide range, and any test for a relationship of this factor with various other parameters was inconclusive. This may be accounted for by the serious difficulty of accurately establishing the trip factors of commercial vehicles, especially because of under-reporting of many short delivery trips in an urban area, or by the various definitions for the linking-up of such trips and for inter- and intra-trips.

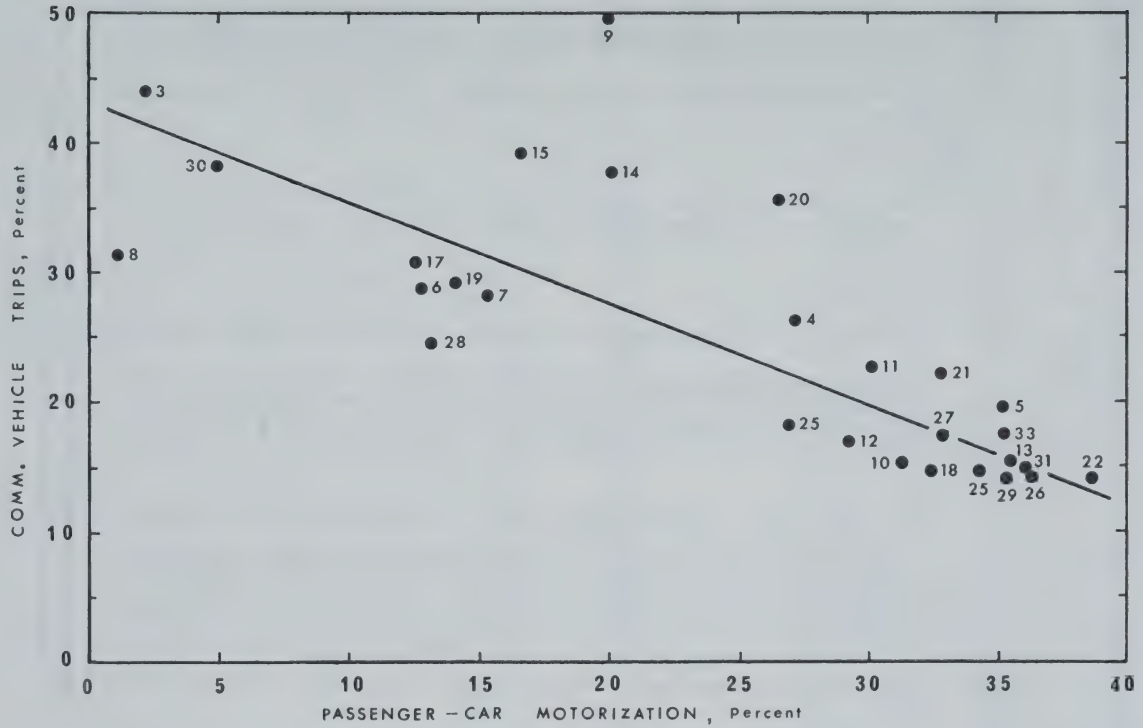
It is recognized that this subject may merit a more careful analysis, but since the probable errors of computing the commercial vehicle trips are wholly within acceptable limits of accuracy for synthesizing transportation patterns, the two relationships presented in this paragraph are considered as sufficient for that purpose.

It is proposed, therefore, to use the average result of these two methods for computing the number of commercial vehicle trips.



COMMERCIAL VEHICLE TRIPS

Fig. 2.10



COMMERCIAL VEHICLE TRIPS AS PERCENTAGE OF PASSENGER CAR TRIPS

Fig. 2.11

Table 2.11

Commercial-Vehicle Trips as Percentage of Passenger-Car Trips

Base - Year

No.	Town	Pass. Car Trips, Int.	Comm. Veh. Trips, Int.	Percentage of Comm. Veh. Trips	Motorization
3	Athens	303,000	127,000	42.0	2.1
4	Baltimore	1,433,356	378,029	26.4	27.2
5	Baton Rouge	409,951	81,431	19.9	35.2
6	Belfast	361,432	103,252	28.6	12.8
7	Birmingham	1,309,938	341,749	28.2	15.4 (1)
8	Bombay	202,000	63,138	31.3	1.0
9	Brisbane	344,835	171,712	49.8	20.0
10	Charleston	379,565	58,493	15.4	31.2
11	Chattanooga	283,000	64,000	22.6	30.2
12	Chicago	4,945,382	827,590	16.8	28.3
13	Columbia	329,892	52,201	15.9	35.5
14	Copenhagen	1,445,300	543,700	37.6	20.1 (2)
15	Dundee	151,090	59,183	39.2	16.6
16	Helsinki	219,600	139,200	63.5	13.0
17	Kingston	226,000	69,100	30.6	12.5
18	Knoxville	362,887	62,827	17.3	32.4
19	London	3,648,742	1,062,419	29.1	14.1
20	Melbourne	1,419,680	518,951	36.6	26.5
21	Monroe	183,196	40,869	22.3	32.8
22	Orlando	594,228	84,231	14.2	38.7
23	Pittsburgh	1,256,535	229,409	18.3	26.9
25	Pulaski	432,084	63,555	14.7	34.2
26	Rapid City	118,992	16,746	14.1	36.3
27	Richmond	542,489	94,140	17.3	32.9
28	Rotterdam	437,737	106,052	24.2	13.1
29	Sioux Falls	176,972	25,317	14.3	35.3
30	Tel-Aviv	309,500	118,750	38.2	4.9
31	Tucson	381,193	56,920	14.9	36.1
33	Winston Salem	242,345	42,560	17.6	35.2

Remarks: (1) Passenger-car trips include M/c trips ;
(2) Passenger-car trips include part of comm.veh. trips.

E. Taxi Trips.

(1) Table 2.12 and Figure 2.12 present the available data of taxi trips for the study-towns. As can be seen, taxi trips constitute a substantial part of the total number of vehicular trips in towns with low levels of motorization, and vice versa.

A marked leveling-off is noticable at a motorization level of about 5-10 per cent. Thus, for some towns on the left-hand side of the curve such trips were added to the total number of trips and Kilometrage at the synthesis phase.

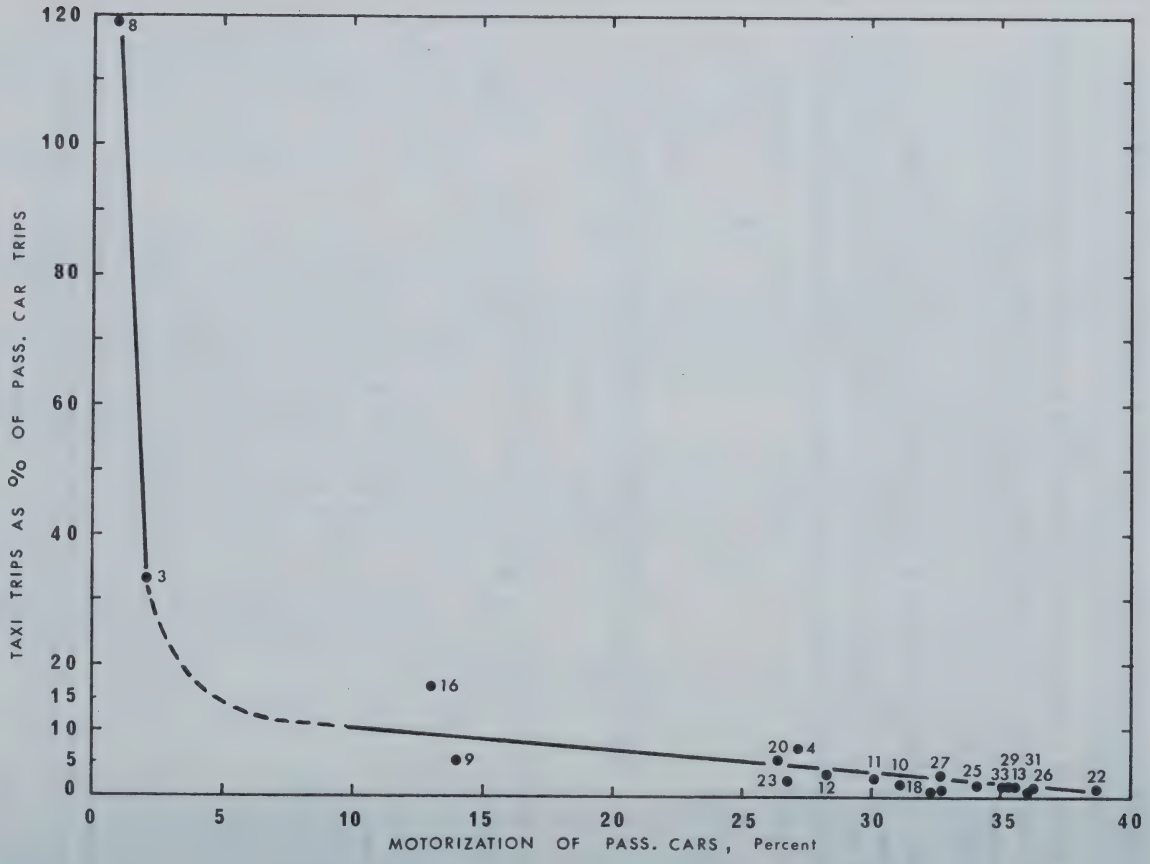
(2) The only study which has mentioned the average trip length of taxi trips is that of London, with an average of 3.5 km. per trip, as compared with 11.2 km. for passenger-car trips. In other words, an average taxi trip-length in London is about 32 per cent of a corresponding length for passenger cars.

Table 2.12

Taxi Trips as Percentage of Passenger-Car Trips

Base - Year

No.	Town	Pass. Car Trips (Internal)	Taxi Trips	Percentage of Taxi Trips	Motorization
3	Athens	303,000	104,000	33.3	2.1
4	Baltimore	1,433,356	103,534	7.2	27.2
8	Bombay	202,000	240,708	119.1	1.0
10	Charleston	379,565	5,507	1.5	31.2
11	Chattanooga	283,000	8,000	2.8	30.2
12	Chicago	4,945,382	171,478	3.5	28.3
13	Columbia	329,892	4,944	1.5	35.5
16	Helsinki	219,600	36,500	16.7	13.0
18	Knoxville	362,887	2,495	0.7	32.4
19	London	3,648,742	183,400	5.2	14.1
20	Melbourne	1,419.680	105,904	5.2	26.5
21	Monroe	183,196	1,504	0.8	32.8
22	Orlando	594,228	5,551	0.9	38.7
23	Pittsburgh	1,256,535	29,102	2.3	26.9
25	Pulaski	432,084	7,406	1.7	34.2
26	Rapid City	118,992	1,320	1.1	36.3
27	Richmond	542,489	16,150	3.0	32.9
29	Sioux Falls	176,972	2,936	1.7	35.3
31	Tucson	384,193	2,064	0.5	36.1
33	Winston Salem	242,345	4,176	1.7	35.2



TAXI TRIPS AS PERCENTAGE OF PASS. CAR TRIPS

Fig. 2.12

It has been assumed, on the other hand, that in towns with very low levels of motorization, taxi trips are more characteristic of passenger-car trips than in towns with medium or high levels of motorization. Thus, the average trip-length of taxis was assumed to be half of that for passenger cars in the synthesis procedure, since taxi trips have been added only in towns with low levels of motorization. Moreover, the average trip length as computed in this research is less than that for passenger cars only, thus raising the relative percentage of the taxi trip length.

F. External Trips.

(1) The external trips relationship was the most problematic one in this research. In most cases it is assumed that the proportion of external trips from the total number of trips is related to the size of the area. For example, the M.I.T. Reprt No. 3, 'Principles and Techniques of Predicting Future Demand for Urban Area Transportation' (Ref. 2.3) says on this subject:- "The proportion of non-resident to resident trips varies, depending upon the size of the urban area. In this research report, we are primarily concerned with urban areas of populations greater than one million, in which this proportion is small (2 to 5%). As urban area size decreases, the proportion of nonresident to resident trips will increase considerably".

This statement may be true for towns in the U.S.A., but it has not been found to be so for all the study-towns in this research, namely from all parts of the world; the scatter was too large for any significant conclusions.

It is believed that the major factor to cause the dispersion is the lack of a definite procedure for defining the external cordon line in relationship to the study area. For example, three main criteria are recognized today for such a definition: (a) It should encompass all major parts of the developed urban area, as well as those parts which are likely to be developed within the planning period of the study;

(b) It should encompass the areas where their populations are daily commuters to the central city of the study; (c) It shuld cut as few entering roads as possible.

Since each one of the above criteria may result in a different cordon line, the final decision is usually based on a compromise with an appreciable leeway.

Moreover, the spatial distribution of population in a country may also be a major factor in influencing the external trip proportion. In England, for example, the spatial distribution of the population is a dense one, thus the proportion of external trips (which include also through-

trips) is a high one. In Australia, on the other hand, the hinterland is a sparse one, thus reducing the external trip proportion to a low value.

Many relationships have been tried in this research, with seemingly relevant and significant parameters, such as population, size of the area, number of vehicles, motorization, density of population, and so on, but with unsatisfactory results.

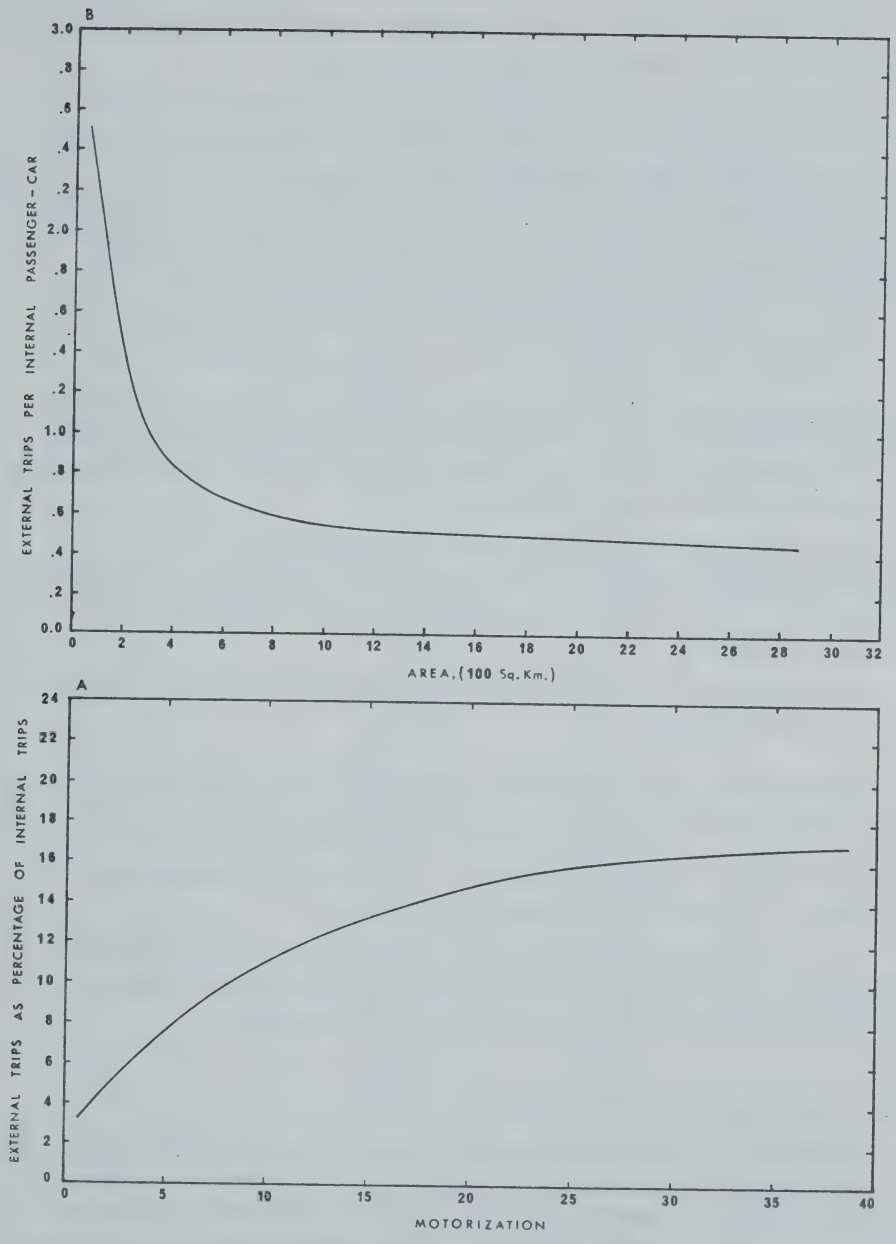
The best results, however, were found to be when combining two relationships together and using the average of their results. These relationships are detailed in Table and Figure 2.13, and they relate the external trips with the area of the study towns and with their motorization levels. The two graphs should, therefore, be used together for deriving the synthesized values for the external trips.

Table 2.13

External Trips

Base-Year

No.	Town	Digram A				Diagram B		
		Mot.%	Total Int. Trips	Total Ext. Trips	% of Ext.	Area	Pass. Cars	Total Ext. Trips per Int. Pass. Car
3	Athens	2.1	430,000	22,300	5.2	448	39,000	0.57
4	Baltimore	27.2	1,811,385	335,090	18.5	2,220	437,540	0.77
5	Baton Rouge	35.2	491,382	71,824	14.6	393	86,116	0.83
6	Belfast	12.8	464,684	97,073	20.9	127	64,248	1.51
7	Birmingham	15.4	1,651,687	273,280	16.6	970	388,353	0.70
8	Bombay	1.0	265,138	7,500	2.8	850	41,679	0.18
9	Brisbane	20.0	516,547	28,060	5.4	970	188,827	0.24
10	Charleston	31.2	438,058	26,534	6.1	1,290	73,360	0.36
11	Chattanooga	30.2	347,000	64,508	18.6	490	72,965	0.89
13	Columbia	35.5	382,093	76,192	20.0	470	69,300	1.10
14	Copenhagen	20.1	1,989,000	40,800	2.1	2,756	342,950	0.12
15	Dundee	16.6	201,273	17,395	8.6	272	34,177	0.51
16	Helsinki	13.0	358,800	33,900	9.5	733	81,488	0.42
17	Kingston	12.5	295,100	62,100	21.0	107	43,183	1.44
18	Knoxville	32.4	425,704	73,073	17.2	1,360	78,374	0.93
19	London	14.1	4,711,161	557,284	11.8	2,450	1,249,453	0.45
20	Melbourne	26.5	1,938,631	85,405	4.4	1,500	517,000	0.17
21	Monroe	32.8	224,065	31,424	14.0	200	31,678	0.99
22	Orlando	38.7	678,459	68,023	10.0	1,400	137,255	0.50
23	Pittsburgh	26.9	1,485,944	307,359	20.7	1,085	395,321	0.78
24	Ponce	8.8	110,449	28,652	26.0	60	11,494	2.50
25	Pulaski	34.2	495,639	71,623	14.5	720	76,337	0.94
26	Rapid City	36.3	135,738	14,972	11.0	276	26,680	0.56
27	Richmond	32.9	636,629	122,181	19.2	346	137,688	0.89
29	Sioux Falls	35.3	202,289	24,883	12.3	147	29,525	0.84
30	Tel-Aviv	4.9	428,250	30,360	7.2	190	39,643	0.76
31	Tucson	36.1	438,113	18,569	4.2	1,580	88,215	0.21
33	Winston Sal'	35.2	284,905	83,374	29.2	400	55,446	1.50
34	Zurich	7.8	480,000	49,200	10.3	402	54,300	0.91



EXTERNAL TRIPS

Fig. 2.13

(2) The general trends in these two graphs may be explained in a consistent way, as follows:-

Graph A: The proportion of external trips increases with the increase in motorization; The increase in motorization increases the mobility of the population, thus it encourages a differential development of the area, where more people with an increasing number of cars tend to move out from the central city and live at increasing distances from it. Thus, even if the external cordon is defined at a relatively large distance from the center (but still at the fringe of the urban development) the proportion of external trips tends to increase with motorization.

Graph B: The number of external trips per internal passenger car tends to decrease with the size of the area; in other words, the greater the area - the greater is the distance from the center- the less vehicle trips are attracted to it.

Thus, two opposing factors have to be considered, where one increases the proportion of external trips, while the other decreases it. By combining the two relationships together, a more realistic result may thus be achieved.

The procedure for applying the two graphs is detailed in paragraph 3(2) of this chapter.

In concluding this paragraph it should be mentioned that the external trips constitute usually a small proportion only of the total number of trips and, therefore, even if the synthesized result deviates to a certain degree from the given one, it does not affect much the total number of trips or Kilometrage in the area.

This paragraph is the last one in the six basic and individual relationships. The next two will deal with the total traffic patterns, namely with the Total Trips and the Total Kilometrage.

G. The Total Daily Vehicle Trips.

(1) Intuitively it would be assumed that the Total Daily Vehicle Trips should be related to the number of vehicles in the study area. This assumption has been tested, therefore, and is presented in Table and Figure 2.14 for base-year data and in Table and Figure 2.15 for target-year data. In these relationships the total daily vehicle trips are related with the registered number of passenger-cars, since this parameter is a more common denominator for the study towns than the total number of vehicles;- in many cases the number of commercial vehicles in not known.

Table 2.14

Total Daily Vehicle Trips

Base-Year

No.	Town	Passenger Cars	Total Trips	Remarks
1	Adelaide	198,800	1,027,500	
2	Amsterdam	56,230	800,000	Within City Proper only
3	Athens	39,000	556,300	
4	Baltimore	437,540	2,250,009	
5	Baton Rouge	86,116	563,206	
6	Belfast	64,248	561,757	
7	Birmingham	388,353	1,924,967	Including M/c trips
8	Bombay	41,679	513,346	
9	Brisbane	118,827	544,607	
10	Charleston	73,360	470,099	
11	Chattanooga	72,965	419,508	
12	Chicago	1,461,646	5,944,450	(No Information on
13	Columbia	69,300	463,229	External Trips.
14	Copenhagen	342,950	2,029,800	
15	Dundee	34,177	227,668	
16	Helsinki	81,488	429,200	
17	Kingston	43,183	356,200	
18	Knoxville	78,374	489,806	
19	London	1,249,453	5,451,845	
20	Melbourne	517,000	2,129,940	
21	Monroe	31,678	256,993	
22	Orlando	137,255	752,033	
23	Pittsburgh	395,321	1,822,405	
24	Ponce	11,494	139,101	
25	Pulaski	76,337	574,668	
26	Rapid City	26,680	152,030	
27	Richmond	137,688	774,960	
28	Rotterdam	139,000	727,283	
29	Sioux Falls	29,525	230,108	
30	Tel-Aviv	39,643	458,610	
31	Tucson	88,215	458,746	
32	West Midlands	388,353	1,734,750	
33	Winston Salem	55,446	372,958	
34	Zurich	54,300	529,200	

The two diagrams summarize, then, a wide spectrum of towns, from different countries, with various sizes, levels of motorization, study procedures, and so on. Nevertheless, the overall picture is quite clear, showing that the total number of trips may be related to the total

registered number of passenger cars. However, a few remarks are in order:-

(a) Base-Year Relationship:

Although the general trend is clear, the dispersion of the points is quite noticeable. Consequently, it would be advisable not to use this relationship for synthesis but rather for comparison and checking purposes only. Namely, this diagram may be consulted after the total number of trips has been computed by the detailed steps of the proposed procedure, which will be explained later on.

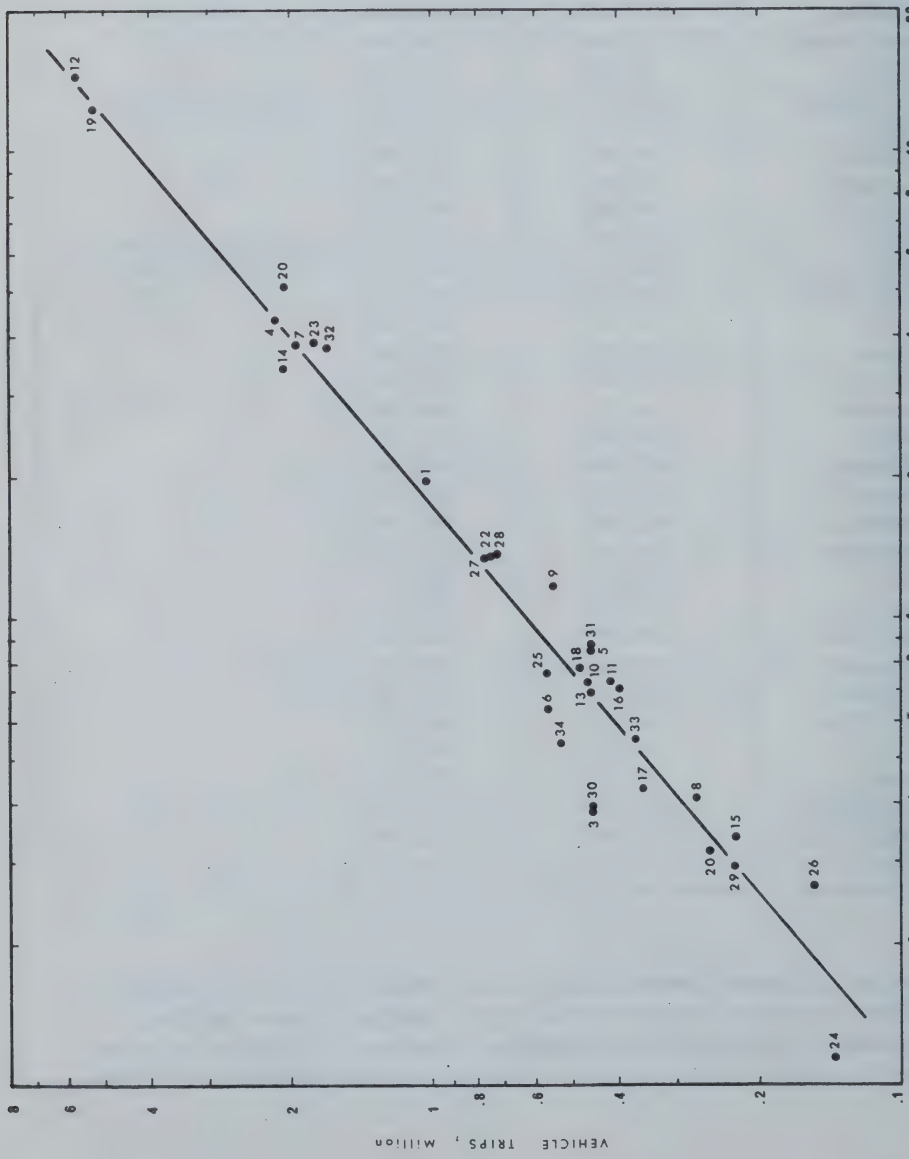


Fig. 2.14

(b) Target-Year Relationship:

This diagram shows the same characteristic trend as for the base-year relationship. Therefore, the same remarks as before apply here as well.

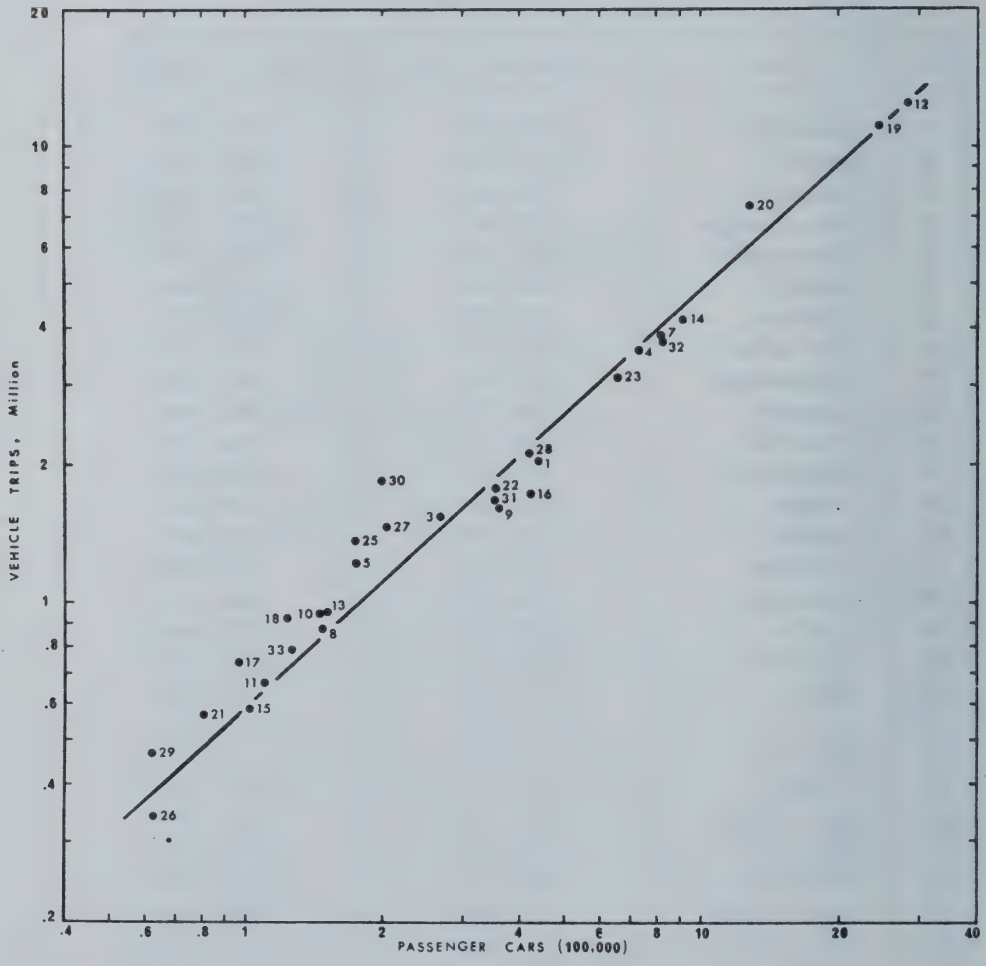
Table 2.15

Total Daily Vehicle Trips

Target-Year

No.	Town	Passenger Cars	Total Trips
1	Adelaide	443,000	2,059,900
3	Athens	270,000	1,837,574
4	Baltimore	734,270	3,586,375
5	Baton Rouge	176,470	1,205,715
7	Birmingham	820,000	3,806,600
8	Bombay	148,753	1,165,196
9	Brisbane	361,270	1,610,583
10	Charleston	146,066	945,858
11	Chattanooga	110,248	669,103
12	Chicago	2,828,000	12,660,994
13	Columbia	150,780	950,116
14	Copenhagen	915,350	4,178,865
15	Dundee	103,408	588,138
16	Helsinki	429,000	1,822,600
17	Kingston	97,170	748,000
18	Knoxville	122,740	825,785
19	London	2,465,000	11,320,000
20	Melbourne	1,291,400	7,509,600
21	Monroe	80,760	574,498
22	Orlando	351,000	1,805,466
23	Pittsburgh	645,263	3,077,923
25	Pulaski	175,178	1,384,963
26	Rapid City	62,550	341,268
27	Richmond	204,434	1,455,619
28	Rotterdam	422,000	2,130,358
29	Sioux Falls	61,900	470,014
30	Tel-Aviv	197,570	1,847,400
31	Tucson	354,000	1,697,400
32	West Midlands	822,000	3,284,700
33	Winston-Salem	127,898	793,056

(2) At this stage, however, it should be emphasized again that the crucial factor for analyzing traffic patterns in an urban area is not the total trips, but rather the total Kilometrage and its distribution on the road network; - it is true that the present comprehensive procedures of a transportation study rely heavily on the O-D trip matrix, but this is so as an intermediate stage only, for computing the vehicle-Kilometrage and its distribution. This principle aspect is of crucial importance for the understanding of the current methods of traffic analysis and planning, which are based on the Kilometrage factor.



TOTAL VEHICLE TRIPS – Target

Fig. 2.15

This is also the reason why it has already been recognized that new procedures for O-D data gathering and processing are so urgently needed.

By considering all the above remarks it may be concluded that the total-trip relationship is not a critical factor in the synthesis procedure and, therefore, should be used for control purposes only.

H. The Total Daily Vehicle Kilometrage.

(1) Table and Figure 2.16 present the relationship between the Total Daily Vehicle Kilometrage and the registered number of passenger cars for base-year conditions, while Table and Figure 2.17 present such a relationship for target-year projections.

(a) Base-Year Relationship:

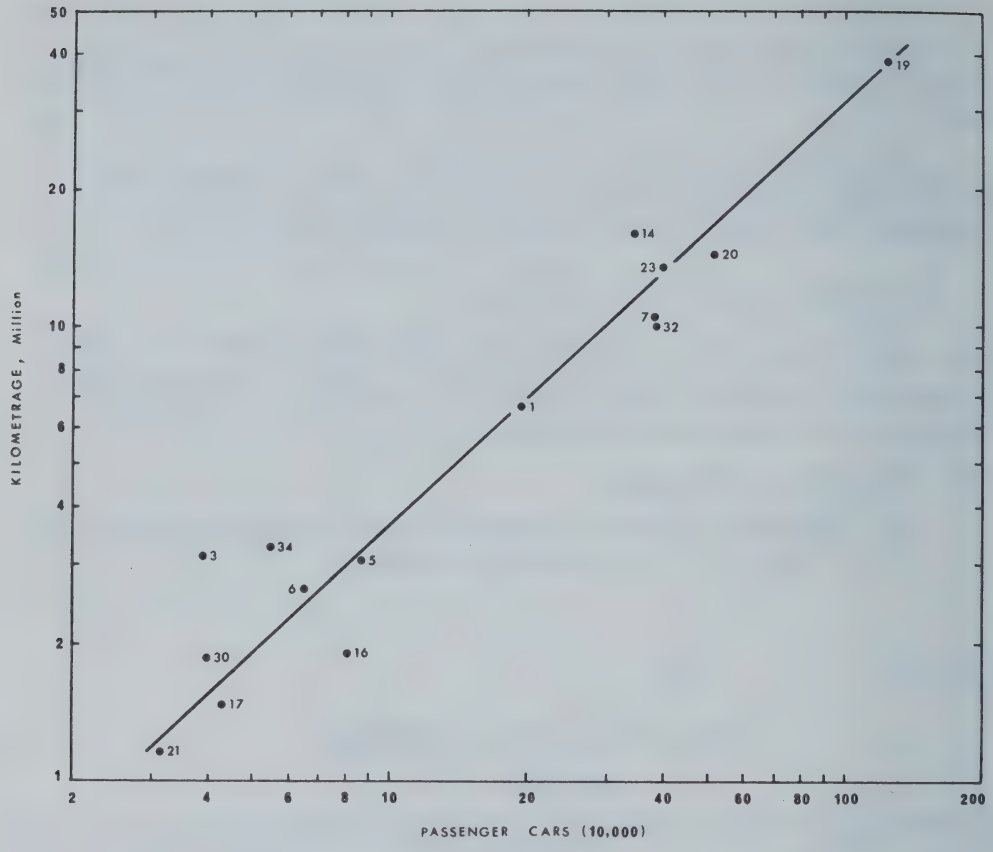
The relationship shows an expected trend, but the dispersion is too wide to be useful for a synthesis procedure.

Table 2.16

Total Daily Vehicle Kilometrage

Base-Year

No.	Town	Passenger Cars	Total Kilometrage (000)
1	Adelaide	198,800	6,625.0
3	Athens	39,000	3,100.0
5	Baton Rouge	86,116	3,025.0
6	Belfast	64,248	2,607.5
7	Birmingham	388,353	10,700.0
14	Copenhagen	342,950	16,038.0
16	Helsinki	81,488	1,899.0
17	Kingston	43,183	1,482.0
19	London	1,249,453	39,200.0
20	Melbourne	517,000	14,600.0
21	Monroe	31,678	1,151.2
23	Pittsburgh	395,321	13,800.0
30	Tel-Aviv	39,643	1,873.3
32	West Midlands	388,353	10,100.0
34	Zurich	54,300	3,267.0



TOTAL DAILY VEHICLE KILOMETRAGE
Base Year

Fig. 2.16

(b) Target-Year Relationship:

Surprisingly enough, the relationship for target years seems to show a much better fit than the one for base-year conditions.

This phenomenon may be of significance since it may have resulted from one or more of several possible explanations. For example: The urban plan (population and land-uses) for the target-year may have smoothed up specific local irregularities, thus directing the future development of the area to a more regular and standard urban structure; The original survey data might have had several unexplained pecularities that were adjusted at the stage of projection; The current methods of projection of traffic and transportation patterns may smoothen up present irregularities; several new factors,

such as a desired ratio of Modal-Split, may have been introduced at the stage of projections, thus compressing the points in the diagram around a desired future condition; and so on.

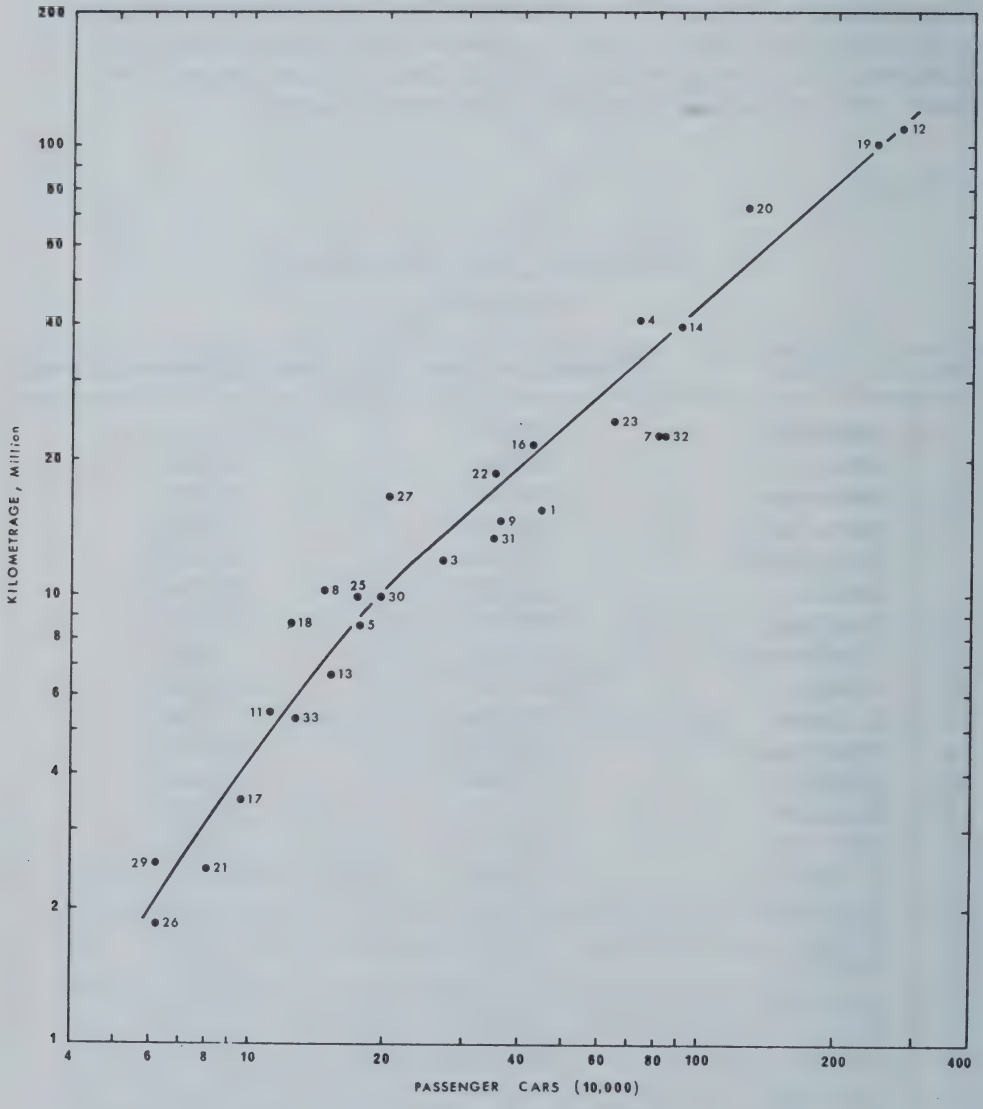
As with the case of the Total Trips relationship, neither this relationship is to be used for synthesizing the Total Vehicle Kilometrage for an urban area, but for control purposes only; namely after the Kilometrage has been derived by the full phases of the proposed procedure. This procedure is detailed in the next paragraph.

Table 2.17

Total Daily Vehicle Kilometrage

Target-Year

No.	Town	Passenger Cars	Total Kilometrage (ooo)
1	Adelaide	443,000	15,000
3	Athens	270,000	12,000
4	Baltimore	734,270	41,000
5	Baton Rouge	176,470	8,500
7	Birmingham	820,000	22,600
8	Bombay	148,753	10,364
9	Brisbane	361,270	14,860
11	Chattanooga	110,248	5,437
12	Chicago	2,828,000	108,700
13	Columbia	150,780	6,620
14	Copenhagen	915,350	39,791
16	Helsinki	429,000	21,649
17	Kingston	97,170	3,503
18	Knoxville	122,740	8,700
19	London	2,465,000	101,650
20	Melbourne	1,291,400	72,450
21	Monroe	80,760	2,460
22	Orlando	351,000	18,660
23	Pittsburgh	654,263	24,200
25	Pulaski	175,178	9,970
26	Rapid City	62,550	1,852
27	Richmond	204,434	16,320
29	Sioux Falls	61,900	2,520
30	Tel-Aviv	197,570	9,891
31	Tucson	354,000	13,480
32	West Midlands	822,000	22,500
33	Winston Salem	127,898	5,280



TOTAL DAILY VEHICLE KILOMETRAGE

Target Year

Fig. 2.17

3. The Procedure for Synthesizing the Daily Kilometrage 'K'.

(1) One of the aims of this thesis is to enable a synthesis of the full transportation data of vehicular traffic for any given town by applying a simple and quick procedure. This paragraph will present, then, such a proposed procedure for the synthesis of the Kilometrage 'K', basing the computation on just three basic area parameters, namely - Population, Motorization, and Area.

Before presenting the procedure, a few general remarks are called for:-

(a) Any traffic model is considered as calibrated and acceptable if it can predict the base-year traffic patterns (such as the traffic volumes crossing various screen-lines) within ± 15 per cent. It has been assumed in this procedure, therefore, that synthesized results within ± 15 % of the given base-year observations are wholly acceptable.

Moreover, projected results to a target-year, some 20-25 years in the future, may be considered as acceptable if they are within even ± 20 per cent of the projections developed by a traffic model, since the probable divergence between the projected future and the expected one increases with time, even when using the most sophisticated model.

This assumption is even more acceptable when considering not only the difficulties encountered while at the stage of gathering field data, or at the stage of comparing studies which have been carried out by so many different procedures, but also when considering the purpose of this procedure, namely - to synthesize the transportation data at a first-approximation level only, by applying not only a simple procedure but by using a minimum number of three basic parameters only.

(b) Isolated results of the synthesis, such as commercial vehicle trips or external trips, should be considered as partial only within the total results, since there is an inherent tendency for counter-balancing the differences when summing-up together all partial results for the final total daily vehicular Kilometrage.

It is of interest to note, however, that the synthesis steps are able to supply data which are not always available in the original study reports, such as the detailed Kilometrage for each separate class of vehicles.

(c) More emphasis should be given to the Kilometrage than to the computed number of trips, not only because it is the purpose of this procedure to define the Factor 'K_d' in Eq. 1.14, but also because the final and crucial part of any transportation analysis is the assignment of the vehicle Kilometrage on the network of roads - whether existing or planned for the future.

(d) The following synthesis steps supply the essential information on the total vehicle travel. At a later chapter several more factors will be added and considered. such as the spatial distribution of the total Kilometrage on the various categories of roads, speeds on them, as well as their desired spatial spacings.

(e) It is believed that the following procedure, and its further development in the forthcoming chapters, will assist in proving the two basic Hypotheses in this Dissertation, namely - that traffic patterns in an urban area may be synthesized easily and rapidly, within acceptable levels of accuracy, by applying only three simple area parameters; - and that the traffic patterns may be synthesized and explained by considering the vehicles as a separate class of 'population' in the area, thus eliminating the need to gather and process many millions of individual trips and other bits of information.

(2) The procedure steps for synthesizing the total daily Kilometrage, whether for base or target years, are as follows:-

Basic Data: (a) Population;
(b) Motorization;
(c) Area.

Step	Description	Source (Fig.)
1	Number of Passenger Cars: Derived by multiplying the Population (a) by the Motorization (b).	-
2	Passenger Car Trip Rate: Derived directly from Fig. 2.3 for base-year and from Fig. 2.4 for target-year.	2.3-2.4
3	Total Number of Pass. Car Trips per Day: Computed by multiplying the number of passenger cars (1) by the Trip Rate (2).	-
4	Radius of the Study Area: Calculated by assuming a circular shape of the study area.	-
5	Average Trip Length: Derived directly from Fig. 2.7 for base-year and from Fig. 2.8 for target-year.	2.7-2.8
6	Daily Kilometrage of Passenger Cars: Computed by multiplying the total number of Trips (3) by the average Trip Length (5). This is a partial result only since the Trip	

Step	Description	Source (Fig.)
	Length is the average for all classes of vehicles, as well as for Internal plus External Trips.	-
7	Number of Commercial Vehicles: The Comm. vehicles, as a percentage of Passenger Cars, are derived directly from Fig. 2.9 for the relevant level of Motorization. The total number of Comm.Veh. is then computed by multiplying the number of Pass. Cars (1) by the derived percentage.	2.9
8	Daily Trips of Commercial Vehicles: Two procedures are proposed:-	
	8a - by deriving the number directly from Fig. 2.10;	2.10
	8b - by deriving the percentage of these trips from Fig. 2.11 and then multiplying it by the total number of Pass. Car Trips (3).	2.11
	It is proposed that the average number of these two methods be used.	
9	Daily Kilometrage of Commercial Vehicles: Computed by multiplying the Daily Trips (8) by the Trip - Length (5).	-
10	Daily Taxi Trips: May be computed for towns with low Motorization levels (less than 5.0%). The percentage of the Taxi Trips can be derived directly from Fig. 2.12 and then should be multiplied by the number of Passenger Car Trips (3).	2.12
11	Average Trip Length of Taxis: Computed by dividing the average Trip Length (5) by two.	-
12	Daily Kilometrage of Taxis: Computed by multiplying the Daily Taxi Trips (10) by the average Taxi Trip Length (11),	-
13	Daily-External Trips: Two procedures are proposed:	
	13a - by deriving the percentage of External Trips from Fig. 2.13 and then multiplying it by the total Internal Trips (3) + (8);	2.13-A

Step	Description	Source (Fig.)
	13b - by deriving the Trip Factor from Fig. 2.13 and multiplying it by the number of Pass. Cars (1).	2.13-B
	It is recommended that the average number of these two methods be used.	
14	Daily Kilometrage of External Trips: Computed by multiplying the External Trips (13) by the average Trip Length (5).	-
15	Total Daily Vehicle Trips: The sum of (3)+(8)+(13). Taxi Trips (10) may be added if desired.	
16	Total Daily Vehicle Kilometrage: The sum of - (6)+(9)+(14). The Taxi Kilometrage (12) may be added if desired.	

(3) This procedure has been applied for all the study towns for base and target years and the synthesized results versus the published data in the original reports are presented in App. 5

Table and Figure 2.18 summarize this comparison for base-year conditions, while Table and Figure 2.19 summarize it for target-year projections.

(I) Base-Year Comparison.

The differences between the synthesized and given data are mostly within a few per cent only, but for extreme cases, such as: (a) For towns where non-standard definitions have been used; (b) Towns for which unexplained deviations in some basic parameters have been noticed.

Nevertheless, it is of interest to note that of the 16 cases for base-year conditions, 4 towns only deviate more than the allowed 15%, and even then most of them are accounted-for by the non-standard defintions in the original study procedures.

(II) Target-Year Comparison.

In this case the scatter in the diagram is more pronounced. However, from the 27 cases only 9 deviate more than the allowed 20%, and even then most of them are accounted for, as will be explained later on.

Table 2.18

Synthesized vs. Given Total Daily Trips & Kilometrage

Base - Year

No.	Town	TRIPS (000)			KILOMETRAGE (000)		
		Synthesized	Given	Diff.%	Synthesized	Given	Diff.%
1	Adelaide	947.0	1,027.5	- 7.8	6,633	6,625	+ 0.1
3	Athens	570.3	556.3	+ 2.5	3,102	3,100	0.0
5	Baton Rouge	473.6	563.2	-15.9	2,842	3,025	- 6.1
6	Belfast	566.3	561.8	+ 0.8	2,377	2,608	- 8.9
7	Birmingham	1,840.8	1,925.0	- 4.4	12,520	10,700	+17.0
9	Brisbane	614.0	544.6	+12.7	4,174	4,036	+ 3.4
14	Copenhagen	1,618.5	2,029.8	-20.2	12,290	16,038	-23.4
16	Helsinki	470.3	392.7	+19.8	3,101	1,899	+63.4
17	Kingston	406.7	357.2	+13.9	1,584	1,482	+ 6.9
19	London	5,674.0	5,268.4	+ 7.7	43,130	39,200	+10.0
20	Melbourne	2,309.0	2,024.0	+14.1	16,623	14,600	+13.9
21	Monroe	244.0	255.5	- 4.5	1,171	1,151	+ 1.7
23	Pittsburgh	1,843.8	1,793.3	+ 2.8	12,898	13,800	- 6.5
28	Rotterdam	715.0	727.3	- 1.7			
30	Tel-Aviv	434.7	458.6	- 5.2	2,043	1,873	+ 9.1
32	West Midlands	1,867.5	1,734.8	+ 7.7	12,880	10,100	+27.5
34	Zurich	496.3	529.2	- 6.2	2,929	3,267	-10.3

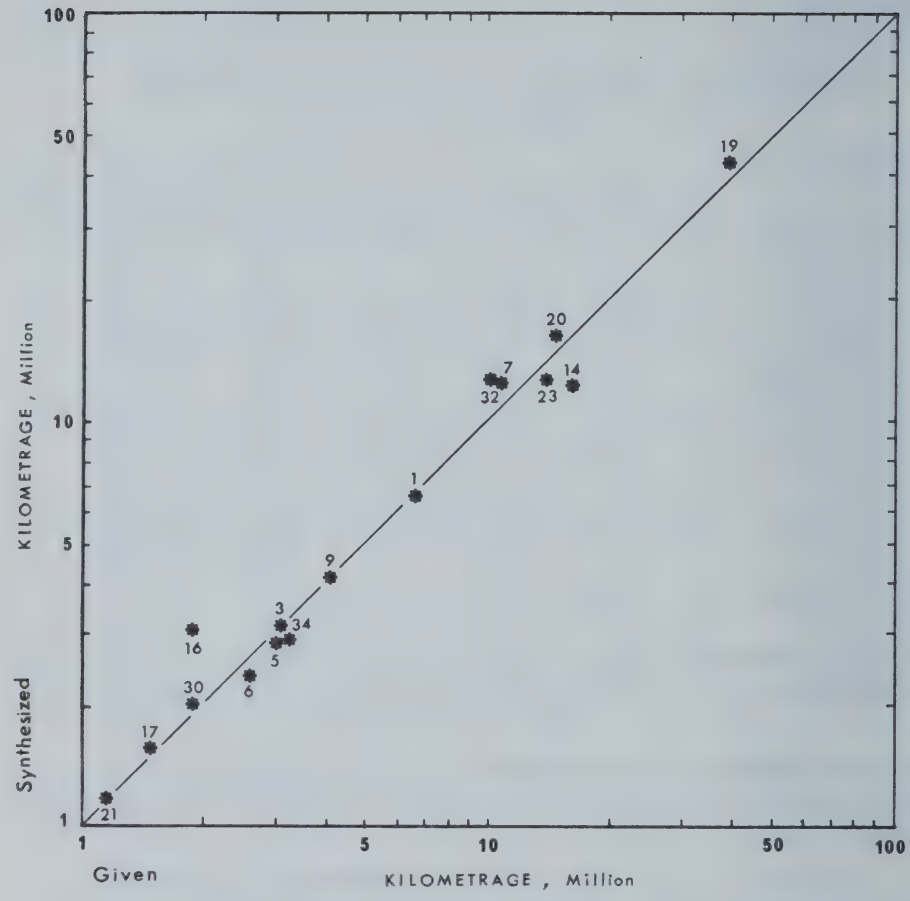
In concluding this comparison, it may be said that in 75% of the cases for base year and 67% for the target-year the synthesized data is within the acceptable limits of accuracy.

Moreover, in the cases where the deviations are above the acceptable levels, some external factors have affected the original data or projections. Following are a few examples:-

(a) Helsinki: The difference for base-year is plus 63.4% but for the target-year it is minus 24.9%. This tendency is not consistent, and by refering again to the Trip-Rate and Trip-Length relationships it is apparent that Helsinki deviates in a strange way from the norm, probably as a result from different definitions.

(b) Copehagen: Part of the commercial vehicles was grouped together with the passenger cars for deriving the number of 'private' trips, thus increasing the base-year data over the synthesized one. The relative difference for the synthesized result is (-) 23.4%. However, since in the target-year the relative weight of this factor will decrease appreciably, the difference comes down to (+) 4.7% only.

(c) Tel-Aviv: For base-year condition the difference is (+) 9.1 %. However, because of the over-estimation in the original report



SYNTHESIZED VS. GIVEN KILOMETRAGE
Base

Fig. 2.18

of the target-year Trip Rate, the difference jumps up to (-) 32.7%. In other words, the synthesized result seems to be more accurate that the one presented in the original report.

(d) West Midlands: The high differences result from the definition of the number of trips in the original report, where linked and unlinked trips of various classes of vehicles are grouped together.

(e) In the cases where the differences are high for target-year, and no data is presented in the original report for base-year conditions, it is impossible to assess the reason for the deviations. However,

for the few cases where such base-year information is included, it may be concluded that the synthesis procedure is quite reliable, since the differences are much more pronounced for the target-year predictions than for the base-year conditions. For instance, the differences, in per cent, for base and target years are as follows:

Adelaide	: (+)	0.1	-	(+) 20.1
Baton Rouge	: (-)	6.1	-	(-) 16.0
Birmingham	: (+)	17.0	-	(+) 45.2
Melbourne	: (+)	13.9	-	(-) 24.6
Monroe	: (+)	1.7	-	(+) 36.1
Pittsburgh	: (-)	6.5	-	(+) 13.1
Tel-Aviv	: (+)	9.1	-	(-) 32.7

It seems therefore that the differences result more from the projection methods used in the studies than from the synthesis procedure.

However, it should be remembered that within this research report the emphasis is put on the analysis - and synthesis - of factual data, for base-year conditions, and not on projected assumptions for a target-year. Thus, it may be concluded that the synthesis procedure - based on the relationships derived from the comparative analysis - may be considered as reliable enough for practical purposes.

Further development of the synthesis procedure will be presented in the following chapters.

(4) In concluding this chapter the question may be raised whether several additional basic parameters should not have been tested with the aim of achieving a higher level of accuracy in the computation of the 'K_d' value.

This crucial question has rather been raised at every step of developing the new procedure, since it is clear that a higher accuracy may be achieved by basing the analysis on as many relevant parameters as possible.

This approach has been demonstrated by the standard procedure of carrying out a comprehensive transportation study, where numerous parameters are being studied and analyzed. On the other hand, that is exactly the reason why a standard procedure in known to be so complicated, lengthy and expensive.

It has been concluded, therefore, that it is preferable to keep the new proposed procedure as simple as possible, at rather elementary levels of two-variable relationships and diagrams, and by

basing it on just three simple area parameters, even if the results may scatter by a few additional percent.

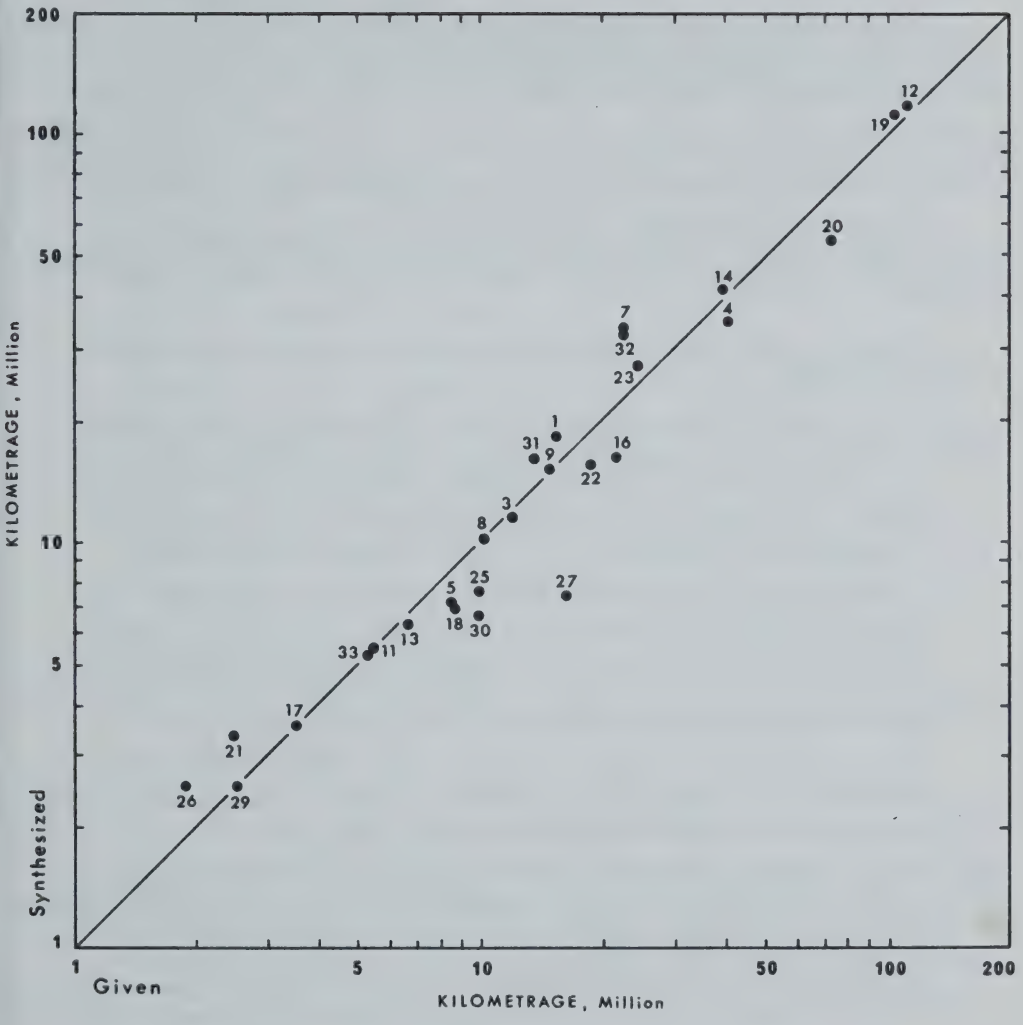
It has been decided, therefore, to sacrifice some accuracy to maintain a simple, straightforward, procedure which may be used easily and quickly not only by Traffic Engineers but also - and particularly so - by Town Planners and City Engineers, for a rapid first-approximation evaluation of the traffic needs for any given town or city.

Table 2.19

Synthesized vs. Given Total Daily Trips & Kilometrage

Target - Year

No.	Town	TRIPS (ooo)			KILOMETRAGE (ooo)		
		Synthesized	Given	Diff. %	Synthesized	Given	Diff. %
1	Adelaide	2,142.5	2,059.9	+ 4.0	18,420	15,335	+20.1
3	Athens	1,685.0	1,837.6	- 8.3	11,580	12,000	- 3.5
4	Baltimore	3,534.0	3,586.4	- 1.5	34,260	41,000	-16.4
5	Baton Rouge	1,034.3	1,205.7	-14.2	7,140	8,500	-16.0
7	Birmingham	3,909.0	3,806.6	+ 2.7	32,800	22,600	+45.2
8	Bombay	1,390.3	1,165.2	+19.3	10,142	10,364	- 2.1
9	Brisbane	1,808.0	1,610.6	+12.2	15,190	14,860	+ 2.2
11	Chattanooga	738.7	669.1	+10.4	5,425	5,437	- 0.2
12	Chicago	12,832.5	12,661.0	+ 1.4	116,750	108,700	+ 7.4
13	Columbia	878.8	950.1	- 7.5	6,325	6,620	- 4.5
14	Copenhagen	4,205.5	4,178.9	- 0.6	41,650	39,791	- 4.7
16	Helsinki	2,057.5	1,736.4	+18.5	16,255	21,649	-24.9
17	Kingston	770.3	748.0	+ 3.0	3,537	3,503	+ 1.0
18	Knoxville	772.3	825.8	- 6.5	6,931	8,700	-20.3
19	London	11,507.5	11,147.0	+ 3.2	112,850	101,650	+11.0
20	Melbourne	6,012.0	7,509.6	-19.9	54,660	72,450	-24.6
21	Monroe	598.6	574.5	+ 4.2	3,349	2,460	+36.1
22	Orlando	1,733.3	1,795.9	- 3.5	15,590	18,660	-16.5
23	Pittsburgh	3,181.5	3,033.8	+ 4.9	27,370	24,200	+13.1
25	Pulaski	988.8	1,385.0	-28.6	7,677	9,970	-23.0
26	Rapid City	413.9	341.3	+21.3	2,565	1,852	+38.5
27	Richmond	1,131.5	1,455.6	-22.2	7,475	16,320	-54.1
28	Rotterdam	2,137.0	2,130.4	+ 0.3			
29	Sioux Falls	505.3	470.0	+ 7.5	2,527	2,520	+ 0.3
30	Tel-Aviv	1,231.0	1,847.4	-33.4	6,655	9,891	-32.7
31	Tucson	1,752.0	1,690.0	+ 3.7	16,105	13,480	+19.5
32	West Midlands	3,931.7	3,284.7	+19.7	33,000	22,500	+46.7
33	Winston Salem	787.5	793.1	- 0.7	5,359	5,280	+ 1.5



SYNTHESIZED VS. GIVEN KILOMETRAGE
Target

Fig. 2.19

CHAPTER 3 : THE ROAD NETWORK

1. Introduction.

In the previous chapter a procedure for synthesizing the total daily vehicle Kilometrage in an urban area was developed and explained.

Since this total Kilometrage is distributed over a complicated network of roads, several principle questions may be raised, such as: (1) Is there a relationship between the categories of roads and the Kilometrage, or any other such parameter; and if the answer is in the affirmative, then: (2) Is it possible to synthesize the network components by a simple procedure, with sufficient accuracry for a first-approximation evaluation?

This chapter will cover these subjects, as well as many other closely related topics. The data for the analysis in this chapter is detailed in Tables 2.1-2.2-2.3.

Before continuing with the analysis, however, a few introductory remarks are called for:-

(a) The lengths of roads considered in the analysis are those defined (coded) for the original assignment in the study towns. However, the network coded for the assignment is not the full inventory of roads in the area, but includes only those that were considered important or essential for the specific assignment procedure.

Such a network usually includes all the Freeways and most - if not all - of the Arterials. As to the Local roads, only a small part of them is usually considered, namely those sections which are used as connecting links between other major roads in the area, or between the centroids and the total network.

It should be noted, therefore, that the less roads defined in the network - the more are the volumes assigned to them, and apparent congestion may result; and vice versa.

(b) Three categories of roads have been defined for the following comparative analysis: Freeways, Arterials, and Locals. These categories may be defined, by their functional use, in the following way:-

Freeway: A road with full control of access to adjoining areas and with full grade separation at junctions, primarily used for long-distance travel within or through the urban area;

Arterial: A major road in the urban area, with intersections at grade and partial control of access, and on which geometric design and traffic control are used to expedite the safe movement of urban through traffic;

Local: A road primarily used for access to adjoining land-uses.

In the original study reports, however, several additional categories of roads may be found, such as Expressways. Moreover, in many cases the data presented combined different categories together, such as Freeways plus Expressways, Expressways plus Arterials, or Arterials plus Locals.

The analysis in this chapter could include, therefore, only those cases in which a full differentiation between the various categories were given.

(c) While discussing the subject of road lengths and categories, an immediate and closely related question is raised, namely the one in regard to their widths; - It is quite understandable that there is a marked difference between a two-lane Freeway and a six-lane one, not only in regard to their capacities and speeds, but also as to their spacings in the area.

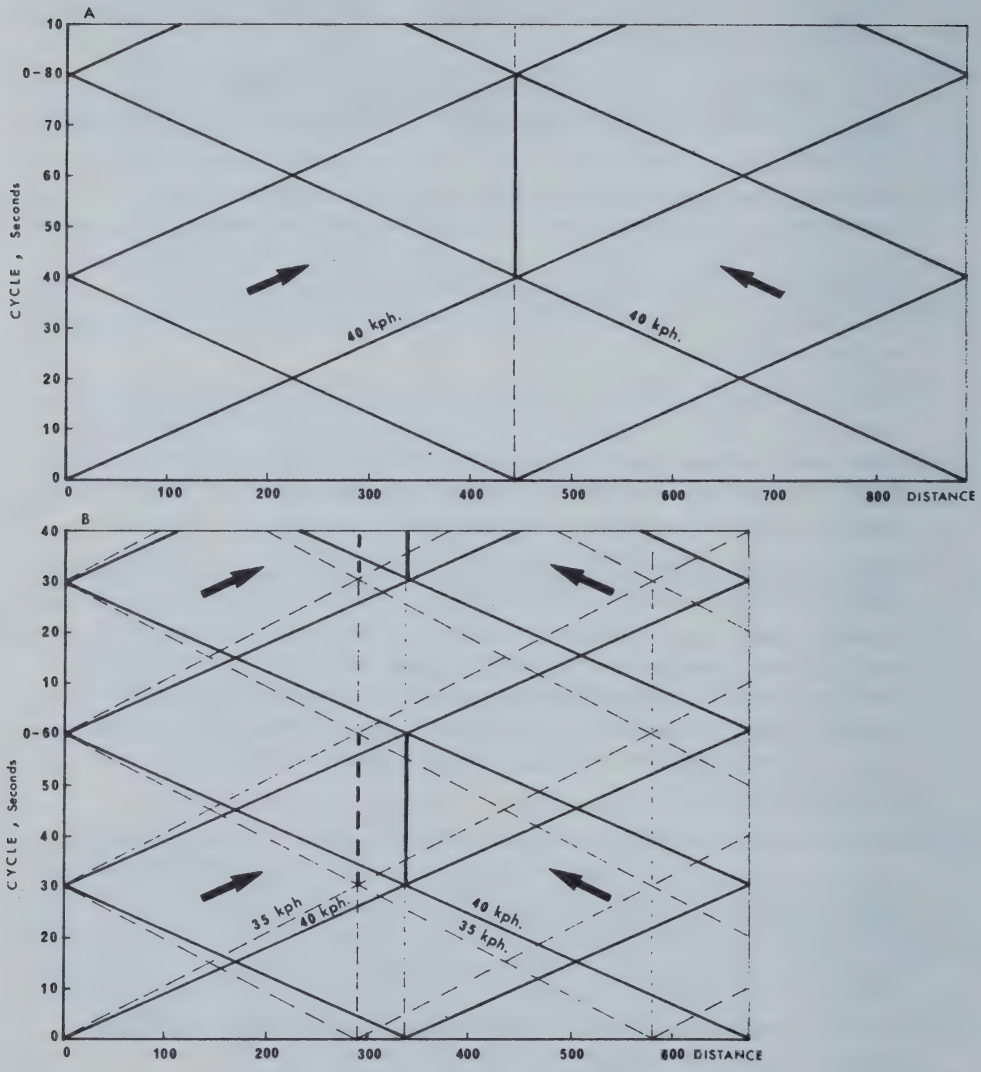
The last subjects, that of spacing, has a special importance in connection with the structure of a town, since in a concentrated town, for instance, with a high density of population and motorization, the widths of roads may have to compensate for the limitation imposed on their lengths or spacings.

Since Freeways are most sensitive to this problem, only towns for which Freeway widths had been given, could be fully analyzed. For Arterial and Local roads, on the other hand, this problem is less critical and, therefore, the road legths, as such, were used to develop several relationships. (However, since the 'IN' model is based on the Dynamic Length of free lanes, it has been necessary to define the widths of the last two categories as well, as will be detailed in chapter 5).

(d) As already has been pointed out in the previous remark, the subject or road-spacing is of major importance for all planners, whether Traffic-Engineers or Town-Planners. It merits, therefore, a further explanation;- For the Traffic Engineer the spacing of Arterial roads establishes the basis for the Time-Space relationship for computing a flexible progressive system of traffic-signals with 'Green Waves' in both directions. Fig. 3.1 presents a simple example of this subject in the following way:-

Let us assume a signal cycle of 80 seconds, of which 40 seconds is the green phase for the Arterial road, and a desired progression speed of 40 kph. It then follows that the optimal spacing of the junctions should be about 445 meters, or multiples of that number.

If it is desired to reduce the spacing then the cycle length, or the progression speed, or both, must be reduced.



TIME-SPACE DIAGRAM OF A 'GREEN-WAVE'

Fig. 3.1

For a cycle length of 60 seconds, for example, and a progression speed of 40 kph, the spacing is reduced to about 335 meters; and by further reducing the speed to 35 kph the road spacing may be reduced to about 290 meters.

It can thus be shown that by considering a practical range of cycle-lengths and progression-speeds, the minimum Arterial spacings are restricted to a certain range, of about 250 - 700 meters.

By considering now the Town-Planner's point of view, entirely different factors have to be considered. For example, the roads divide the area into blocks in which land-uses have to be integrated. Thus, the Town-Planner has to take into account not only the division of the land-uses into practical planning-blocks, but also to consider the human-factor of proportions and environmental scales.

It is true that the relatively new method of planning large pedestrians precincts or malls for human activities has alleviated by some degree the limitations and pressures imposed on the planner (since land owners would prefer 4-corners to each small lot), but still such diversified factors show why a close cooperation between the Town-Planner and the Traffic-Engineer is so desirable - and sometimes even essential - for an optimal planning of the road network.

That is also one of the reasons why the understanding of the subject of road-spacing is of such importance in the analysis of road networks.

After pointing out above a few general remarks and considerations, it is time now to come back to the detailed analysis of the networks of the three categories of roads defined in this research.

2. Freeways.

(1) The Length of Freeways:

The first question raised is whether there is a relationship between the length of the Freeways and any parameter of the area.

Much research has been carried out on this subject, as well as other related topics, and a concentrated presentation may be found in the booklet 'System Considerations for Urban Freeways' (ref. 3.1), from where Figure 2 is shown here as Fig. 3.2.

At this stage, however, a most important factor should be considered:- all comparative analyses of Freeway networks should be conducted on the basis of the planned networks for a target-year, and not the existing networks; existing networks represent intermediate stages only - and sometimes even just several sections - of an integrated comprehensive plan, and thus can not be representative of the operational characteristics of a Freeway network.

That is why all Freeway analyses, whether in previous research studies or in this Dissertation, are based on the complete planned network.

It should also be pointed out at this stage that the Freeway network plans, as shown in Fig. 3.2, or given in the published reports of the study-towns, represent the present planning-philosophy of Freeway networks in urban areas, but not necessarily that this planning-philosophy is right and that those Freeways are a must for the towns studied. There is much controversy going-on all around the world on this subject, which is beyond the scope of this research. This research is mainly concerned with the analysis and development of a simple procedure by which the traffic demands and results of current planning methods may be synthesized and evaluated.

1. Atlanta
2. Baltimore
3. Boston
4. Buffalo
5. Chicago
6. Cincinnati
7. Cleveland
8. Dallas
9. Detroit
10. Houston
11. Jacksonville
12. Los Angeles
13. Miami
14. New York
15. Philadelphia
16. Pittsburgh
17. St. Louis
18. San Francisco
19. Seattle
20. Washington, D.C.

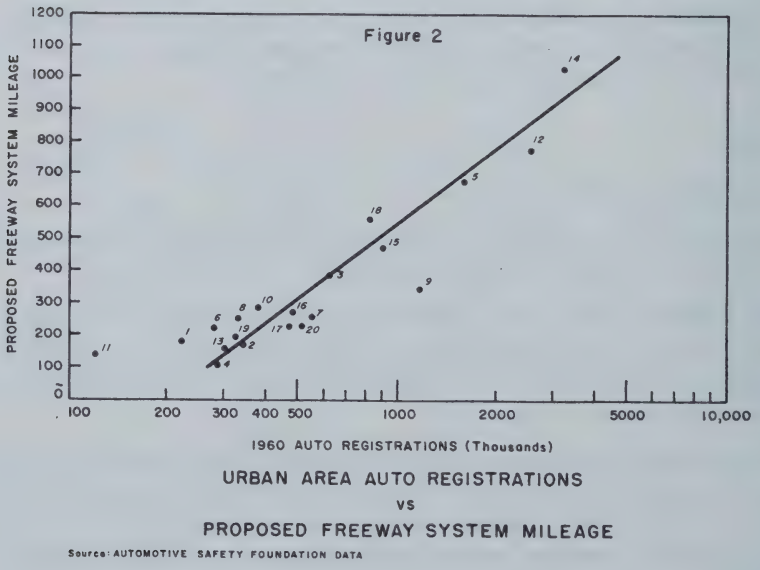


Fig. 3.2

Coming back to Fig. 3.2, it should be noted, therefore, that the relationship shows the planned networks. However, and strangely enough, these networks are shown versus the 1960 number of registered cars in the areas. Since this is not only a questionable procedure, but the dispersion of the points is quite noticeable, the relationship developed for the study - towns in this research is based on the comparable target-year networks and passenger-cars, as detailed in Tab. 3.1. and Fig. 3.3.

The general trend is quite clear, where the length of Freeways tends to increase with the increase in the number of cars. However, this relationship is not satisfactory enough, especially for the lower range of car population, where a dispersion is noticeable.

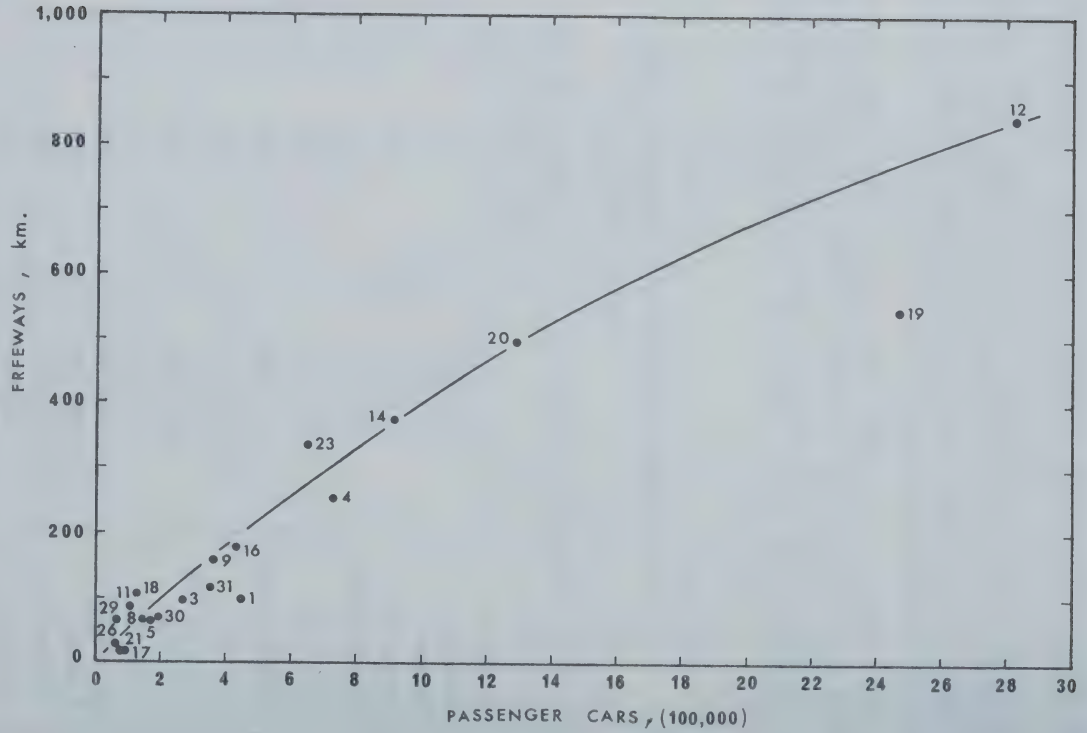
It has been assumed, therefore, that such a relationship is not complete as long as the widths of the Freeways are not included in the analysis. That is why a second relationship has been tested, for those towns for which widths had been given in the study reports, as presented in the following paragraph.

Table 3.1

Freeway Networks vs. Passenger Cars

Target-Year

No.	Town	Passenger Cars	Freeway Network Road Length, km.
1	Adelaide	443,000	98
3	Athens	270,000	96
4	Baltimore	734,270	250
5	Baton Rouge	176,470	61
8	Bombay	148,753	67
9	Brisbane	361,270	155
11	Chattanooga	110,248	86
12	Chicago	2,828,000	840
14	Copenhagen	915,350	374
16	Helsinki	429,000	175
17	Kingston	97,170	17
18	Knoxville	122,740	104
19	London	2,465,000	542
20	Melbourne	1,291,400	495
21	Monroe	80,760	18
23	Pittsburgh	654,263	338
26	Rapid City	62,550	27
29	Sioux Falls	61,900	63
30	Tel-Aviv	197,570	68
31	Tucson	354,000	116



FREEWAY NETWORK LENGTH

Fig. 3.3

(2) Lane-Length of Freeways:

Information on the widths of Freeways was given in 10 study-towns only, out of 34, as detailed in Tab. 3.2. This table includes information on additional 7 towns, from another source. Thus, 17 points were available for analysis.

As can be seen in Fig. 3.4, the total lane length of the Freeways may be correlated with the number of cars. Moreover, a few towns which were far from the average curve in the previous relationship in Fig. 3.3 have now been related in a closer way. For example, Adelaide and London (points 1 and 19 respectively) are far from the average curve in Fig. 3.3, but when their lane lengths are considered, they are highly conforming with the general trend. It has thus been concluded that the lane-length parameter should be used for all further Freeway analysis.

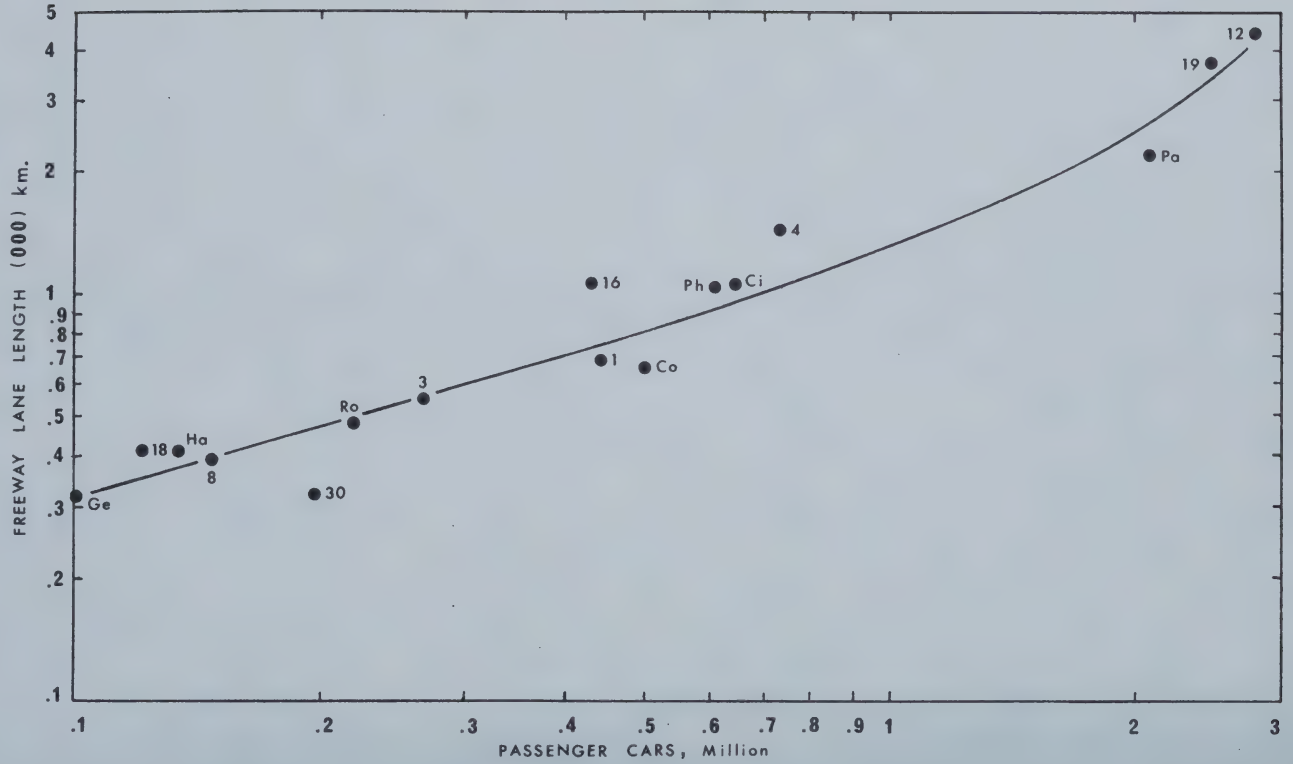
Table 3.2

Freeway Lane Length vs. Passenger Cars

Target - Year

Sources: (a) The Transportation Studies;
(b) The Sixth International Study Week in Traffic Engineering, Salzburgh, 1962.

No.	Town	Year	Passenger Cars	Freeway Length, Km.	Width Lanes	Freeway Lane Length, Km.
1	Adelaide	86	443,000	98	7.0	682
3	Athens	80	270,000	96	5.8	558
4	Baltimore	85	734,270	250	5.8	1,450
8	Bombay	81	148,753	67	5.9	395
12	Chicago	80	2,828,000	840	5.3	4,450
16	Helsinki	2000	429,000	175	6.1	1,068
17	Kingston	81	97,170	17	4.9	84
18	Knoxville	82	122,740	104	4.0	416
19	London	81	2,465,000	542	6.9	3,745
30	Tel-Aviv	85	197,570	68	4.8	326
Ci	Cincinnati	80	646,000	210	5.0	1,050
Co	Copenhagen	80	500,000	117	5.6	655
Ge	Gelsenkirchen	85	100,000	76	4.1	312
Pa	Paris	75	2,100,000	430	5.1	2,200
Ph	Phoenix	80	610,000	227	4.5	1,020
Ro	Rotterdam	80	220,000	85	5.7	485
Ha	The Hague	80	135,000	84	5.0	420



FREEWAY LANE LENGTH

Fig. 3.4

(3) The Kilometrage on Freeways:

The next crucial question is whether the Kilometrage assigned to a Freeway network may be correlated with any parameter of the area?

To answer this question a comparative analysis of the available data is presented in Tab. 3.3. and Fig. 3.5. As can be seen, there is a strong tendency for the assigned Kilometrage to be correlated with the number of cars in the area;- when their number is low, at just about 70-100,000 the planned Freeway network is a rudimentary one, thus attracting about 20 per cent only of the total daily Kilometrage; However, with the increase of the car population above 100,000 and up to about 350,000 there is a rapid increase in the percentage of the assigned Kilometrage. After that a saturation level is reached, with about 55 per cent of the Kilometrage assigned in Freeways for any number of cars over 500,000.

It should be noticed, by the way, that three available base-year conditions have been added to the relationship, for a better presentation of the curve at its lower left side.

Since the other two categories of roads are also represented in Fig. 3.5, a few general remarks are in order:-

(a) Although the dispersion in this figure is quite noticeable, the general trend is clear, and may be used for a first-approximation division of the total daily Kilometrage between the three categories of roads. (as will be seen later on, several additional and independent methods are available for reassessing this division).

(b) The assigned Kilometrage on the Local network seems to be quite constant, with an average of about 8-10% of the total. (See definition of the Local network in parg. 1 (a)).

(c) The Arterial network is complementary to the Freeways, and balances the difference between Freeways and Locals.

At this stage the question may be raised whether there is a relationship between the assigned Kilometrage on the Freeway network and its lane length.

To answer this question the Kilometrage density and the lane density of the 10 study-towns have been analyzed, as detailed in Tab. 3.4 and presented in Fig. 3.6.

As can be seen, a most definite and consistent relationship emerges. (A linear relationship, although curved on the semi-log. scale).

It may be concluded, therefore, that notwithstanding the wide ranges of town sizes, local conditions, methods of projections, policies, and

Table 3.3

Proportions of Assigned Kilometrage on Road Categories

No.	Town	Year	Pass. Cars	Total K (000)	Freeways		Arterials		Locals		Remarks
					K	%	K	%	K	%	
1	Adelaide	T	443,000	15,335	4,020	26.2	8,175	53.3	3,140	20.5	A & E
3	Athens	T	270,000	12,000	5,800	48.3	5,450	45.5	750	6.2	
4	Baltimore	T	734,270	41,000	21,900	53.5	(19,100)	(46.5)	-	-	A & L
5	Baton Rouge	B	86,116	3,025	100	3.3	2,570	85.0	355	11.7	
	" "	T	176,470	8,500	1,970	23.2	(6,530)	(76.8)	-	-	A & L
8	Bombay	T	148,753	10,364	3,310	32.0	6,440	62.1	614	5.9	
9	Brishbane	T	361,270	14,860	7,570	51.0	(7,290)	(49.0)	-	-	A & L
11	Chattanooga	T	110,248	5,437	1,930	35.5	3,220	59.2	287	5.3	
12	Chicago	T	2,828,000	108,700	55,400	51.0	53,300	49.0	-	-	No Locals
16	Helsinki	B	81,488	1,899	260	13.7	(1,487)	(78.3)	152	8.0	A & E
	"	T	429,000	21,649	9,779	45.2	(10,539)	(48.7)	1,331	6.1	A & E
17	Kingston	T	97,170	3,503	728	20.7	1,945	55.6	830	23.7	
18	Knoxville	T	122,740	8,700	3,120	35.9	4,750	54.6	830	9.5	
19	London	T	2,465,000	101,650	55,200	54.5	(46,450)	(45.5)	-	-	A & L
20	Melbourne	T	1,291,400	72,450	37,000	51.1	27,400	37.8	8,050	11.1	
21	Monroe	B	31,678	1,151	43	3.7	960	83.5	148	12.8	
	"	T	80,760	2,470	430	16.7	(2,040)	(83.3)	-	-	A & L
26	Rapid City	T	62,550	1,852	459	24.8	(1,393)	(75.2)	-	-	A & L
30	Tel-Aviv	T	197,570	9,891	3,422	34.6	4,767	48.2	1,702	17.2	
31	Tucson	T	354,000	13,480	(6,130)	(45.4)	6,350	47.2	1,000	7.4	F & E

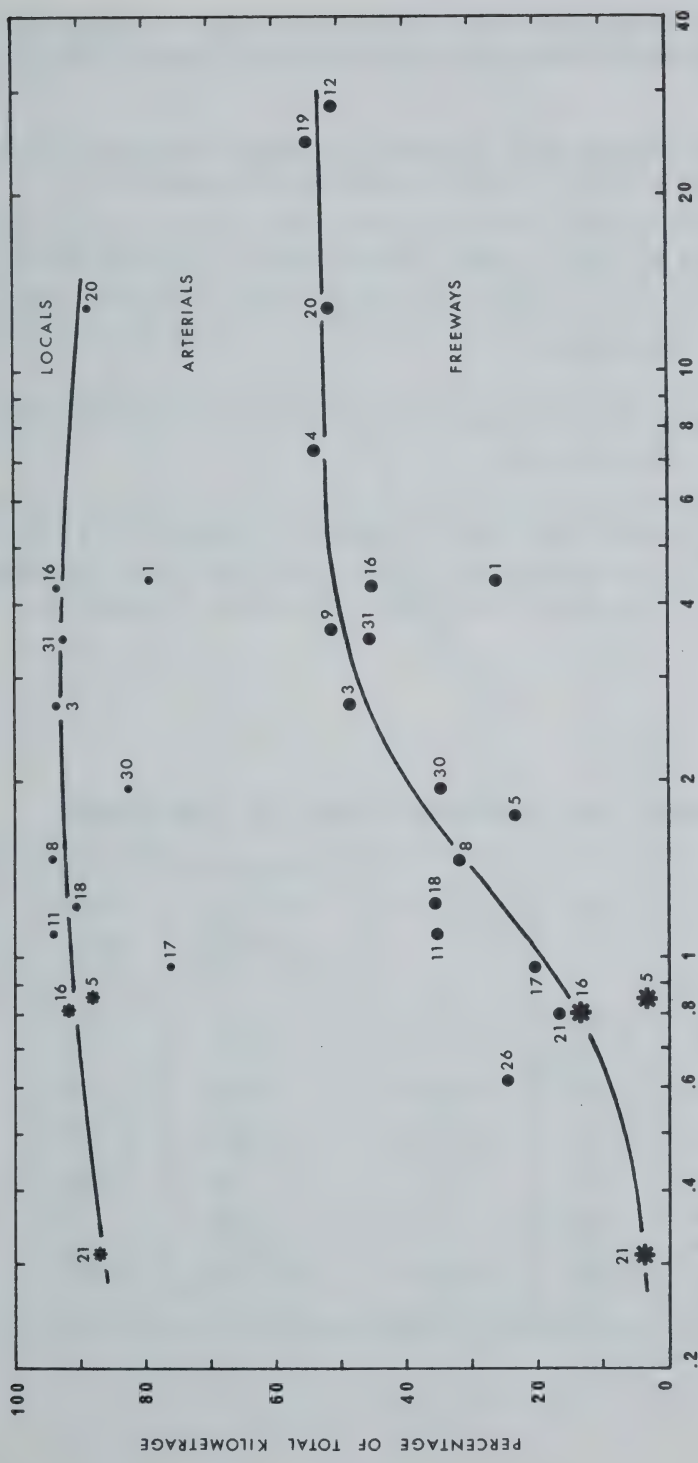

PERCENTAGE OF TOTAL KILOMETRAGE
100
80
60
40
20
0
.2
.4
.6
.8
1
2
4
6
8
10
20
40
PASSENGER CARS, (100,000)
LOCALS
ARTERIALS
FREEWAYS
KILOMETRAGE ON FREEWAYS
ARTERIALS AND LOCALS

Fig. 3.5

standards of planning, the overall correlation is clear, namely that the Freeway Kilometrage density and the Freeway lane density are highly correlated.

This relationship will, therefore, be used extensively for synthesizing Freeway networks, as will be detailed in chapter 5.

Until now the two basic components of a Freeway network have been defined, namely the daily assigned Kilometrage and the lane length, as well as the interrelationship between the two. However, these two components are average only, for the whole area, without knowing how to distribute them over the urban area.

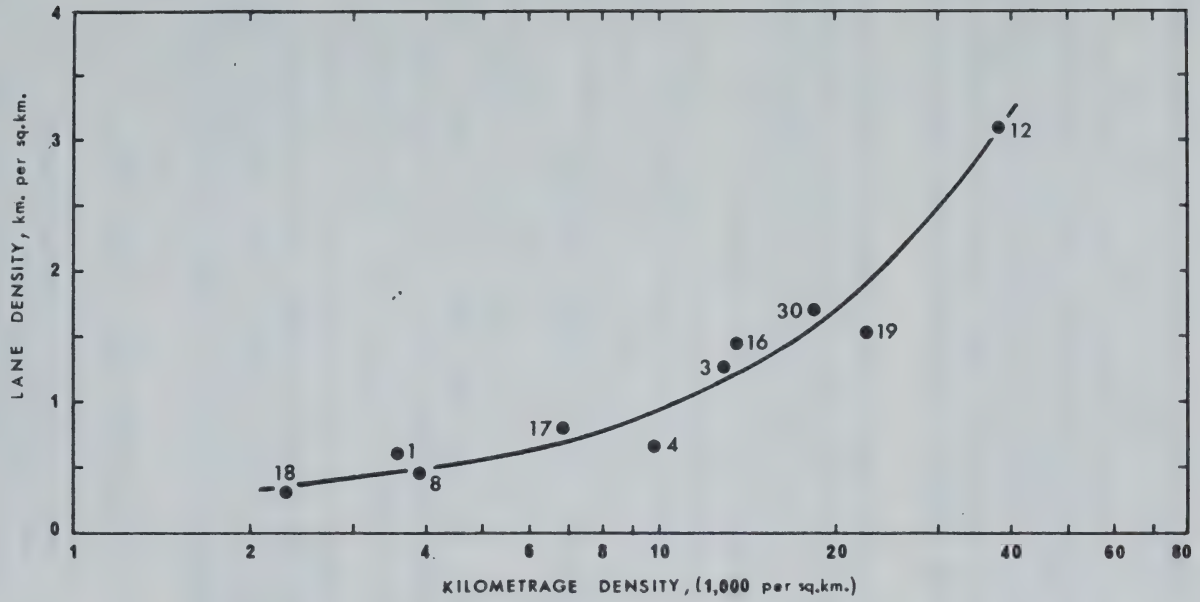
It may be assumed, on the other hand, that their distribution will have to be closely related to the relative intensities of the travel patterns and demands in the urban area.

The general subject of how to synthesize the distribution of Kilometrage over an urban area will be discussed in chapter 5. At this stage, therefore, the analysis will continue with the subject of Freeway spacing, since it is a major component of the spatial structure of a Freeway network.

Table 3.4

Freeway Daily Kilometrage Density vs. Lane Density

No.	Town	Area	Daily Kmt. (ooo)	Kilometrage Density ($\frac{\text{veh. km.}}{\text{sq. km.}}$)	Lane Length (km.)	Lane Density ($\frac{\text{km.}}{\text{sq. km.}}$)
1	Adelaide	1,120	4,020	3,590	682	0.61
3	Athens	448	5,800	12,950	558	1.25
4	Baltimore	2,220	21,900	9,860	1,450	0.65
8	Bombay	850	3,310	3,900	395	0.46
12	Chicago	1,430	55,400	38,800	4,450	3.12
16	Helsinki	733	9,779	13,350	1,068	1.45
17	Kingston	107	728	6,820	85	0.80
18	Knoxville	1,360	3,120	2,300	416	0.31
19	London	2,450	55,200	22,550	3,745	1.53
30	Tel-Aviv	190	3,422	18,100	326	1.72



FREEWAY DENSITIES

Fig. 3.6

(4) Freeway Spacings:

The problem of Freeway spacing has come up in every transportation study and many procedures have been developed for the purpose of solving it.

Two such examples may be mentioned here, those by the Chicago and Penn-Jersey studies.

The Chicago procedure proposes a mathematical method for determining "the spacing which minimizes community transportation costs". Fundamental to the technique is the hypotesis that, for a given area, a value of spacing can be found such that the sum of the construction costs entailed in providing that spacing plus the travel costs resulting on the entire transportation system is less than it would be for any greater or lesser spacing.

The input requirements for that technique include:- Freeway construction cost per kilometer; speed on Freeways and Arterials; vehicle trip densities per sq.km.; a constant representing the money value of travel time; and a function representing the distribution of trip length between Local, Arterial and Freeway facilities.

Not only is this technique based on too many parameters for a simple synthesis procedure, but at least one of them - that of vehicle trip densities in rings around the center - is beyond the scope of the procedure developed in this thesis; since it is based on the total values of the vehicle population, and not on individual trips.

The second technique, which was used in the Penn-Jersey transportation study, is a more direct technique than the Chicago one, relying on traffic data only. But once again, one of its principal parameters is the density of vehicle trip origins, which is beyond the scope of this thesis.

That is why a different approach has been considered, as follows.

There are many possible ways by which the spacings of Freeways (or any other category of roads) may be computed rapidly with a minimum number of parameters, and without the need for trip information. Following are three examples of such elementary relationships, where it is assumed that the network is orthogonal:-

(a) From Eq. 5.2 (see chapter 5) it follows that -

$$L = n \sqrt{A} = n.a \; ; \qquad (3.1)$$

Where: L - total length of free lanes;
n - number of free lanes entering an area;
A - area, in sq.km.;
a - one side of a square area.

Since the spacing of roads (or individual lanes, depending on the definition) for a square area is -

$$S_p = \frac{a}{\frac{1}{2} n} \quad ;$$

it follows that -

$$S_p = \frac{a}{\frac{1}{2} n} = \frac{2\ a.a}{L} = \frac{2\ A}{L} \quad ; \qquad (3.2)$$

This elementary formula, which may be found in many articles (for example, Ref. 3.2), simply says that the spacing is proportional directly to the area and inversely to the length of roads included in that area.

(b) The hourly Kilometrage for a network may be expressed by -

$$K_h = q.L \quad ; \qquad (3.3)$$

where 'q' is the average volume per lane and 'L' is the total length of lanes. It then follows that -

$$K_h = q.L = q.n.\sqrt{A} = q\frac{2.A}{S_p} \quad ; \qquad (3.4)$$

$$\therefore \quad S_p = \frac{2\ q\ A}{K_h} \quad ; \qquad (3.5)$$

This second elementary formula expresses the spacing of lanes as a function of the area, the hourly Kilometrage assigned to this area, and the average volume (or planned capacity) per lane.

It should be noted that this formula expresses the spacing of lanes entering an area. This formula should be modified, therefore, if roads, each with several lanes, are considered.

(c) Coming back to Fig. 3.6, another formula may be developed, to express the relationship between the density of Kilometrage and the density of Freeways, as follows:- If we assume an infinite area covered with a rectangular grid of roads, then -

If: a,b - are the sides of each cell (spacing);
D - the lane density per sq.km.;
M - average number of lanes per road;

Then the following relationship should hold true -

$$a + b = \frac{D(a.b)}{M} \quad ; \qquad (3.6)$$

$$\therefore \quad \frac{1}{a} + \frac{1}{b} = \frac{D}{M} \; ; \qquad (3.7)$$

And if the cells are square shaped, where a = b, it then follows that -

$$S_p = a = \frac{2\,M}{D} \; ; \qquad (3.8)$$

Since this formula is for an infinite network only, a correction factor 'Q' has to be introduced when a finite network is considered, where -

$$S_p = \frac{2\,M}{D} \; x \; \frac{1}{Q} \; ; \qquad (3.9)$$

The values of 'Q' are presented in Tab. 3.5 for various configurations of the Freeway networks. If the network is composed, for instance, of a square of 4 cells, then the 'Q' factor is 1.5 and the spacing will have to be reduced by this value.

Table 3.5

Freeway Spacing Correction-Factor 'R'

$$Q = \frac{\text{Sides}}{2 \text{ x No. of Squares}} \; ;$$

Squares	Sides	'Q'	Configuration of the Freeway Network Cells
1	4	2.00	
2	7	1.75	
3	10	1.67	
4	13	1.63	
4	12	1.50	
5	15	1.50	
6	16	1.60	

Based on formula 3.8 it is now possible to develop a family of curves expressing the average spacings of Freeways for different values of kilometrage densities and the number of lanes. This is detailed in Tab. 3.6 and Fig. 3.7.

At this stage a computed example may better explain the relationship: - The recommended Transportation Plan for Tel Aviv Metropolitan Area includes four cells of Freeways with an average spacing of 3.8 km. (Four cells with dimension of 2.1 x 2.9; 2.7 x 4.2; 3.5 x 4.1; 4.3 x 8.2 km). The average Kilometrage density for the Freeway network is 18,000 veh. km/sq.km., and the average number of Freeway lanes is 4.8. It then follows that the computed average spacing should be -

$$S_p = \frac{2 \times 4.8}{1.7} \times \frac{1}{1.5} = 3.77 \text{ km.};$$

which is in full agreement with the planned average spacing of 3.8 km. (The value of 1.7 has been computed in Tab.3.4)

However, it should be noted that not all Freeway networks are necessarily cellular in structure, since many may be composed of just one cell encompassing the center and with radial arms radiating from it. In such cases there is no meaning anymore to the 'average spacing' and therefore the above procedure is not wholly applicable.

Table 3.6

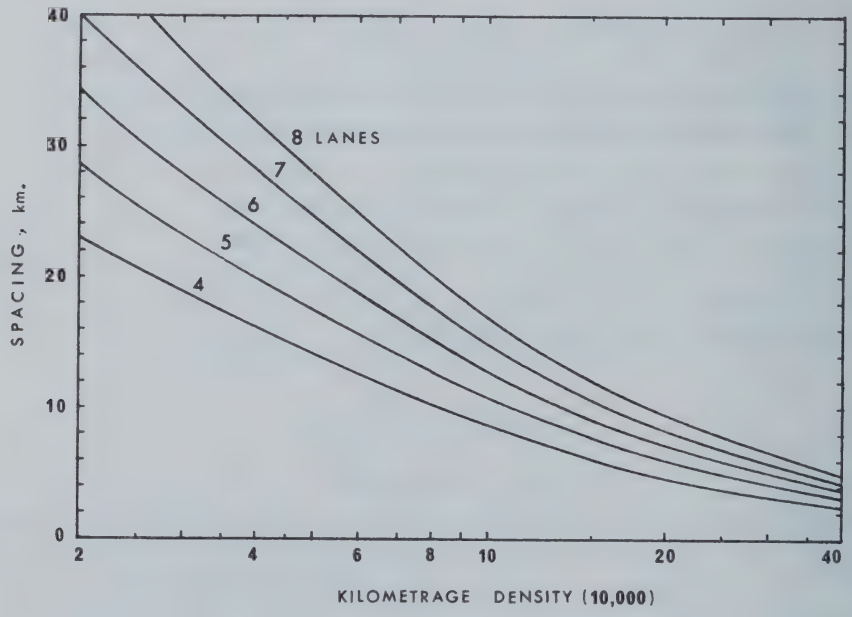
Freeway Spacings

Daily Kilometrage Density	Lane Density	Grid Spacing, Km. Average number of Lanes				
		4	5	6	7	8
2,000	0.35	22.9	28.6	34.3	40.0	45.7
3,000	0.43	18.6	23.3	27.9	32.6	37.2
5,000	0.57	14.05	17.6	21.0	24.6	28.1
7.500	0.75	10.70	13.3	16.0	18.7	21.4
10,000	0.95	8.43	10.52	12.62	14.73	16.85
15.000	1.32	6.06	7.58	9.10	10.60	12.12
20,000	1.67	4.80	6.00	7.18	8.38	9.59
30,000	2.45	3.27	4.07	4.90	5.70	6.54
40,000	3.20	2.50	3.13	3.75	4.38	5.00

The procedure should, therefore, be used only when contemplating a cellular structure of the Freeway network. However, this is usually the case with Freeway networks.

Up to now an average spacing has been discussed but since traffic in a town is not homogeneously distributed over the area, it is quite clear that an average value of spacing - though important - can not adequately answer the demand.

A further development of the procedure will, therefore, be presented in the next chapter, showing how the Freeway network - or any other network - may be distributed in an urban area in accordance with local traffic intensities and demands.



FREEWAY SPACINGS

Fig. 3.7

3. Arterials.

(1) The Kilometrage - Road Length Relationship.

As with the case of Freeways, the subject of Arterial analysis has already intensively been covered by many studies. A concentrated resume' may be found in the booklet 'System Considerations for Urban Arterial Streets' (Ref. 3.3.)

The analysis procedure of the Arterial networks is basically the same as that for Freeway networks, but with one major difference; - only in one or two cases was the average number of lanes (or the total lane-length) detailed in the published reports of the study-towns. Moreover, even this kind of information is not enough in the case of Arterials, since it is more important to know if lanes are free to move traffic. But, unfortunately, this kind of information is rarely - if at all - detailed in the study reports.

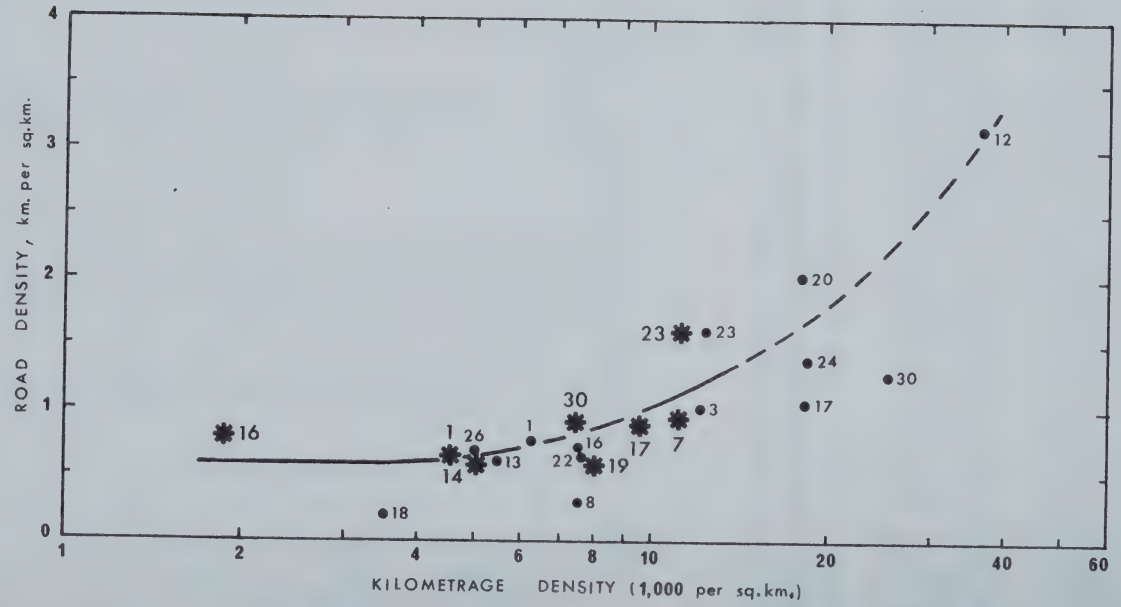
It should be expected, therefore, that the data, if based on the road-length only, would show a wide scattering in any comparative analysis. The basic data and the results of the analysis are detailed in Tab. 3.7 and Fig. 3.8.

Nevertheless, and in spite of all the above limitations, a most useful relationship emerges again. In this figure, base-year as well as target-year information are presented together, for a better evaluation of the trends.

Table 3.7

Arterial Daily Kilometrage Density vs. Road Density

No.	Town	Year		Area	Assigned Kilometrage (ooo)	Kilometrage Density	Road Length	Road Density
1	Adelaide	65		1,120	5,170	4,620	755	0.67
	"		86	1,120	7,000	6,250	855	0.76
3	Athens		80	448	5,450	12,180	458	1.02
7	Birmingham	62		970	(10,700)	11,100	920	0.95
8	Bombay		81	850	6,440	7,570	246	0.29
12	Chicago		80	1,430	53,300	37,300	4,500	3.15
13	Columbia		85	470	(2,570)	5,470	283	0.60
14	Copenhagen	67		2,756	12,951	4,700	1,480	0.54
	"		85	2,756	13,800	5,000	1,765	0.64
16	Helsinki	66		733	1,380	1,880	586	0.80
	"		2000	733	5,529	7,550	536	0.73
17	Kingston	67		107	1,045	9,770	96	0.90
	"		81	107	1,945	18,200	111	1.04
18	Knoxville		82	1,360	4,750	3,500	244	0.18
19	London	61		2,450	19,850	8,100	1,435	0.59
20	Melbourne		85	1,500	27,400	18,300	3,060	2.04
22	Orlando		85	1,400	10,900	7,800	864	0.62
23	Pittsburgh	58		1,085	12,250	11,300	1,750	1.61
	"		80	1,085	13,250	12,200	(1,750)	1.61
24	Ponce		85	60	1,122	18,700	84	1.40
26	Rapid City		85	276	1,393	5,050	193	0.70
30	Tel-Aviv	65		190	1,433	7,550	172	0.90
	" "		85	190	4,767	25,100	243	1.28
31	Tucson		80	1,580	6,350	4,020	935	0.59



ARTERIAL DENSITIES

Fig. 3.8

Two major conclusions may be drawn from the relationship of the Kilometrage density versus the road length density:-

(a) Up to density of about 10.000 veh.km. per sq.km., the base-year Arterial density remains practically constant. After a second thought this result is quite an expected one, since in all cases the Arterial network in existing towns had practically been defined - and built - on the basis of town-planning considerations, including the sizes of blocks, and not on traffic considerations.

Consequently, the road density remains constant, or rather within a limited range of dispersion of 0.6-0.9 for all veh. Kilometrage densities in base-year data, thus reflecting the standards of town-planning in the past.

(b) Even most of the target-year planning seems to center on the same range, although it seems to be more traffic-oriented, when higher road densities are considered for higher Kilometrage densities. However, there does not seems to be a well-defined criterion for Arterial densities for target-year data, and the scatter is noticeable. An additional test, using the average daily volume per 1-km. length of Arterial roads, has shown a wide range of planning standards, between the range of 9,000 - 26,000 veh. per 1-km. of road per day, which may explain the scatter.
Nevertheless, the scatter seems to follow the base-year general trend, thus showing that no drastic change for the planning standards of Arterials is being considered for future implementation, and in most cases less than double the existing densities. (It should be noted that the curved line on the semi-log scales in Fig. 3.8 represents an approximately linear relationship.

2 Arterial Spacings.

As in regard to the spacing of Arterials, the same basic formulas developed for Freeways are also applicable in this case, although the factor 'R' may be ommitted here, since the many arterials in the study area - compared to the few Freeways - may practically be regarded as an infinite network.

Tab. 3.8 and Fig. 3.9 present the spacing value computed for various Kilometrage densities.

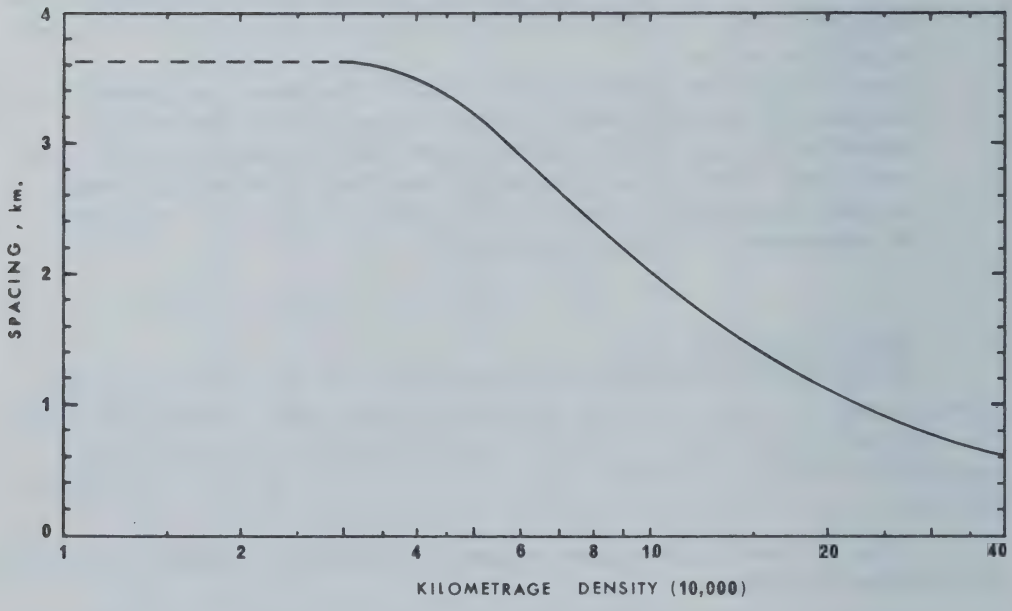
However, in the case of Arterial spacing at least two more factors have to be considered, as already mentioned previously, namely the size of blocks and the progressive system of traffic-signals.

Table 3.8

Arterial Spacings

$$\text{Spacing} = \frac{2}{\text{Road Density}}$$

Kilometrage Density	Road Density	Spacing, Km.
1,500	0.55	3.64
2,000	0.55	3.64
3,000	0.55	3.64
5,000	0.62	3.23
7,500	0.80	2.50
10,000	1.00	2.00
15,000	1.40	1.43
20,000	1.80	1.11
30,000	2.60	0.77
40,000	3.35	0.60



ARTERIAL SPACINGS

Fig. 3.9

In regard to the second factor, Fig. 3.10 shows the spacing as a function of the average progression speed and cycle lengths. This figure is based on the simple relationship -

$$\text{Spacing (m)} = \frac{\text{Speed (meters ph) x Cycle (sec.)}}{3{,}600 \text{ (sec.p.h.)}} \qquad (3.10)$$

and the numerical data is presented in Tab. 3.9.

Table 3.9

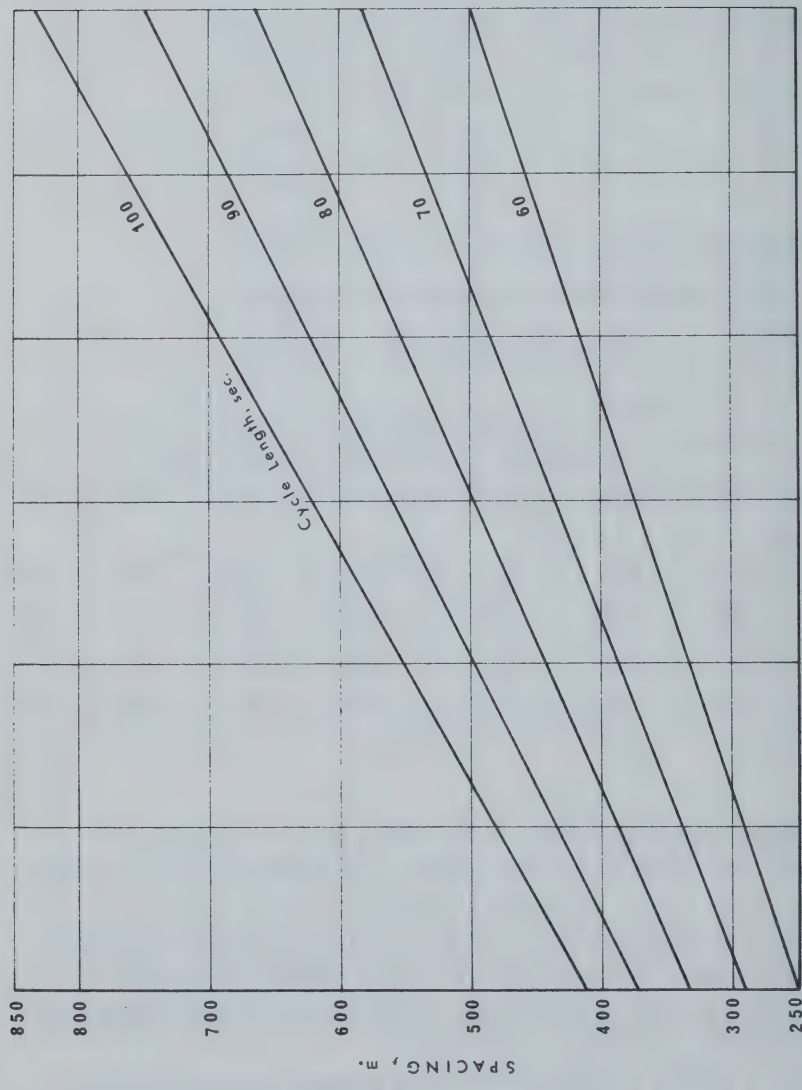
Arterial Spacing in Relation to Cycle Length of Traffic Signals and Maximum Possible Progressive Speeds

Cycle Length of Green Waves (Sec.)	Arterial Spacings, Meters Maximum Progressive Speeds, Kph.						
	30	35	40	45	50	55	60
60	250	292	333	375	417	458	500
70	292	340	389	438	486	533	584
80	333	389	445	500	555	610	667
90	375	437	500	562	612	687	750
100	416	486	555	625	695	765	835

The practical spacings seem to be, then, from a minimum of about 250 meters and up to about 700 meters, or multiples of the values.

In other words, when planning an Arterial network for the town proper, the above two considerations, of block size and junction spacing, may have to be evaluated and decided upon first, while the number of lanes for the resulting road network can be derived at a later stage, after applying the procedure proposed in this report.

However, it should be noted again that average values only have been discussed up to now, and that for a complete planning procedure a detailed distribution of the Kilometrage on the network has still to be made. This basic problem will, therefore, be discussed in the next chapters.



ARTERIAL SPACING
VS. CYCLE LENGTHS OF SIGNAL 'GREEN-WAVES'

Fig. 3.10

4. Locals.

(1) The Kilometrage - Road Length Relationship.

The Local network is usually considered as a peripheral subject in the reports of transportation studies, not only because the Kilometrage assigned to it is quite low, but also because the network itself is mostly decided upon by strictly local planning considerations (such as access frontage to the bordering land-uses) and not by traffic demand considerations.

The relationship between the Kilometrage density and the road length density is detailed in Tab. 3.10 and Fig.3.11, where base and target years' data are presented side by side.

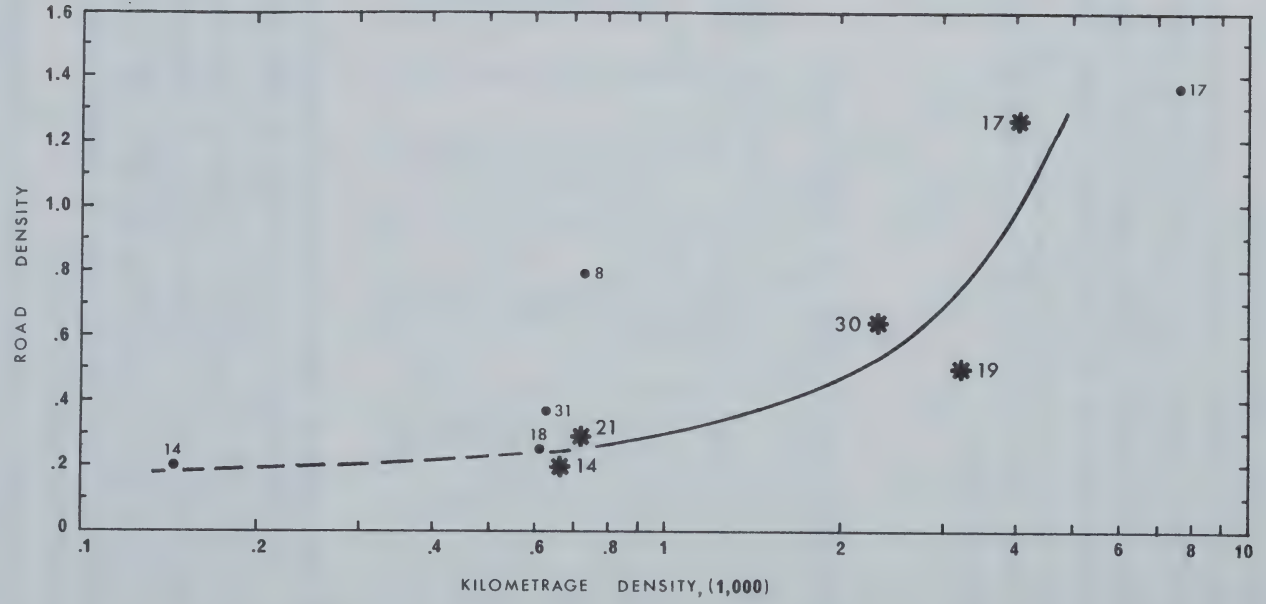
Table 3.10

Local Kilometrage Density vs. Road Density

No.	Town	Year		Area	Assigned Kilometrage (ooo)	Kilometrage Density	Road Length	Road Density
8	Bombay		81	850	614	722	670	0.79
14	Copenhagen	67		2,756	1,859	675	545	0.20
	"		85	2,756	391	142	(545)	0.20
17	Kingston	67		107	437	4,080	136	1.27
	"		81	107	830	7,750	147	1.37
18	Knoxville		82	1,360	830	610	345	0.25
19	London	61		2,450	7,950	3,240	1,228	0.50
21	Monroe	65		200	148	738	59	0.29
30	Tel-Aviv	65		190	441	2,320	121	0.64
31	Tucson		80	1,580	1,000	633	582	0.37

And again the same general trend as with the Arterials comes to light. However, while the base-year relationship is quite consistent, thus reflecting actual conditions, the target-year projections are widely scattered. This may apparently be explained, as already mentioned above, by the fact that in most cases the Local network is not considered to be important enough - traffic-wise - to warrant a detailed planning effort, especially so in the general transportation plan for 20 or so years to come, and the Local network is left over for the stage of detailed local planning by Town Planners and Traffic-Engineers.

However, one important phenomenon should be emphasized; there seems to be a marked tendency for the Local network densities to increase sharply with the increase of Kilometrage densities, even at quite low densities.



LOCAL DENSITIES

Fig. 3.11

It would be advisable, therefore, that more attention should be given to this category of roads in the future, more so because the Arterials and Freeways are interchangeable in a way, but there is no alternative for a Local network, especially for access roads to the land-uses.

Moreover, it is quite a known fact that as the vehicle population in a town with no Freeways increases, severe difficulties appear on the Local network, if by over-spiling of traffic from the Arterials or by the elimination of free Local lanes by parking.

It may be concluded, therefore, that although more emphasis is being put today on the Freeway and Arterial networks in a comprehensive transportation plan, it would be advisable to give more attention than in the past to the Local network, both from the traffic and environmental points of view.

* *

At this stage most of the basic components of a road network have been defined, although as total values - or averages - for the whole urban area.

The next stage, therefore, will be to define a procedure by which these totals may be distributed over the urban area proportionally to the actual, or projected, travel demands.

Such a method will be explained in the following chapter 4, while its application procedures, as well as further development of the 'IN' model, will be presented in chapter 5.

* * *

CHAPTER 4: TRAFFIC MODELS.

1. Introduction.

With the rapid development of the motor vehicle population, and the resulting traffic congestion and towns' deterioration during the last 2-3 decades, it was only natural and expected that more and more specific attention be given to the development of new concepts and procedures in the fields of transportation and traffic analysis. Outstanding within this framework was the Traffic Model.

The present mathematical procedures for the development of the traffic model has already been presented in the Introduction. It may be classified into three basic parts: (1) The estimation of the number of generated and attracted trips by each separate traffic zone within the urban area; (2) The Distribution of the trips between all the zones in the area; and (3) The assignment of the matrix of trips between the zones to a road - or public transport - network.

In this chapter, however, only the second part of the traffic model will be discussed, namely that of distributing the trips between the zones.

The importance of traffic models lies in their ability to create traffic patterns for a given set of assumptions, thus enabling the forecasting of traffic demands for any future time or situation. Traffic models are, therefore, an analytical tool by which future traffic patterns may be better estimated, for a more reliable and founded procedure of planning.

It is of interest to note, however, that traffic models owe their origin to the pioneers of social research, who more than a century ago - even before the invention of the motor-vehicle - had already developed the basic concepts of such models for the purpose of explaining the behaviour of people within various systems, such as Geographic, Demographic, Social and Economic Systems.

It was H.C. Carey who had already in 1858 formulated in his 'Principles of Social Science' the following concept:-

> "Man tends of necessity to gravitate towrds his fellowman. Of all animals he is the most gregarious and the greater the number collected in a given sphere the greater the attractive force there exerted. Gravitation is here, as everywhere else in the material world, in the direct ratio of the mass, and the inverse one of the distance".

Thirty years later, in 1885, E.G. Ravenstein was perhaps first to classify migrants in terms of distance spanned and to show with statistical data that the extent of migration into a given center of absorption from a given point varies, in general, inversely with the distance separating the two.

Four years later, in 1889, an Austrian railway-man, Eduard Lill, has proposed an analogy of Newton's law of gravitation to a railway network, by assuming it to be a linear system in a field with an approximately uniform distribution of traffic poles.

Thirty-five years later, in 1924, E.G. Young has expressed the movement of population to a center by the same general Newton's analogy, namely by relating the intensity of attraction as inversely proportional to the square of the distance to the center. ("The movement of farm population", Cornell Agricultural Experiment Station, Bulletin No. 426, 1924).

Five years later, in 1929, W.J. Reilly has extended the same analogy to retail trade by formulating his 'Law of Retail Gravitation' as follows:-

> "Two cities attract retail trade, primarily shopping goods, from an intermediate city or town in the vicinity of the breaking point, approximately in direct proportion to the population of the two cities and in the inverse proportion to the square of the distance from these two cities to the intermediate town".

Most of the definitions up to now show a clear resemblance to the classical Law of Universal Gravitation, already formulated by Newton in 1672, which simply states that there is a force of attraction between any two masses m_1 and m_2 which is directly proportional to the product of the masses and inversely proportional to the square of their distance apart, namely -

$$F = \frac{m_1 \cdot m_2}{r_{12}^2} \qquad (4.1)$$

Where 'G' is a positive constant called the 'Constant of Gravitation'.

It was only from 1948 onwards, however, that this type of a physical model has rigerously been further developed and applied to many socio-economic relationships. J.Q. Stewart, in his many papers (Ref. 4.1), as well as G.K. Zipf (Ref. 4.2), simultaneously gave the major impetus to the gravity model development, although several other researchers have in the meantime used the same relationship, such as Pallin in 1930 (Ref. 4.3.).

The gravity model has since been adopted by traffic researchers (such as J.D. Carroll in 1955, Ref. 4.3), and further developed with many variations for computing inter-area or inter-zonal traffic volumes, as will be discussed in the following paragraph.

Moreover, not only was the gravity model 'borrowed' and adopted from the field of Social Sciences, but even the quite recent 'Intervening Opportunities' model, first used in the Chicago Transportation Study in

1960, was originally developed by S.A. Stouffer while attempting to generalize the relationship between migration and distance, as published in the 'American Sociological Review' in 1940 (Ref. 4.4.).

For a better understanding of the concepts behind traffic models it is, perhaps, best to revert back to the basic ideas underlying the sociological models as, for example, those developed by Stewart.

2. The Gravity Model in Social Sciences.

In the Natural Sciences there are laws such as those governing the density, pressure, and temperature of gases that were discovered only because matter was investigated as a mass. Stewart reasoned that similar relations might underline the interaction of social units, such as people, which relations could be discovered only by investigating large aggregates of such units. He then formulated three primary concepts based on Newtonian physics, as follows:-

(1) The 'Demographic (Gravitational) Force', F, attracting between two groups of people P_i and P_j separated by distance r is given by -

$$F = G' \frac{P_i \times P_j}{r_{ij}^2} \quad ; \qquad (4.2)$$

Where F acts along the line joining the two groups and G'is a constant.

(2) Accordingly, their 'Demographic (Gravitational) Energy', by virtue of this force, is given by -

$$D = G' \frac{P_i \times P_j}{r_{ij}} \quad ; \qquad (4.3)$$

(3) The 'Demographic (Gravitational) Potential' which the group of P_j individuals produce at the point 'i' (where the group P_j is located) is given by -

$$_iV_j = G' \frac{P_j}{r_{ij}} \quad ; \qquad (4.4)$$

Thus, the total Potential at any point 'i' produced by the entire population of many such groups, may be taken as the sum of the separate Potentials produced by each group, namely -

$$_iV = G' \frac{P_1}{r_{i1}} + G' \frac{P_2}{r_{i2}} + \ldots\ldots\ldots + G' \frac{P_n}{r_{in}} = \sum_{j=1}^{n} \frac{P_j}{r_{ij}} ; \qquad (4.5)$$

(it is to be noted that any mass at 'i' creates potential upon itself. If the distance of this mass from 'i', namely r_{ij}, is taken as zero, the value of $_iV$ becomes infinite. Therefore, it becomes necessary to conceive of any mass at 'i', or concentrated around 'i', as being located at some finite distance from 'i'; usually as a ratio of the radius of the area 'i').

Stewart has put much emphasis on the concept of 'Demographic Potential' and after conducting many empirical studies has reported high correlation within the U.S.A. of the spatial variation of population potential with spatial variation in a wide variety of sociological phenomena, such as rural population density, farmland values, etc., or even miles of railroad track per square mile.

At this stage it should be noted that the exponent r_{ij} in the 'Demographic Force' formula is given the value of 2, corresponding to the exponent of 2 in the classical Gravitational Force formula. However, many empirical studies of behaviour, particularly in the field of traffic in towns, have indicated that appropriate values for the exponent may lie within a wide range, between 0.5 and 3.5. The higher the exponent the greater is the 'friction' of distance on interaction.

Thus, the measurement of distance is not as simple a matter as it would seem. In economic, social, or even psychological terms, 10 kilometers is not simply equivalent to 10 times 1 kilometer, or 10 kilometers over flat plain is rather different from 10 kilometers across mountaineous terrain.

The difficulty of finding an appropriate function for distance in theoretical models of behaviour has led to attempts to define distance by some other measure. In the transportation gravity model, for example, time of travel is usually used, as well as cost of travel, or a combination of both. However, although time in transportation is a better measure than the physical distance, the classification of trips by purpose, even within the same town, has complicated the issue since the exponent had differed for each separate trip-purpose. For instance, Prof. W.R. Blunden mentions the following range of exponent by purpose: Work Trips - 0.5 - 2.0; Shopping; Personal - 1.5 - 2.0; Business, Recreational - 2.0 - 2.5; All Purposes - 1.5 - 2.5. ('Introduction to Traffic Science', Traffic Eng. & Cont., Feb. 1967).

However, the adopted Gravity Model suffers from severe drawbacks not only because it is used in a two-dimensional framework of people - whereas the physical gravity formula is for a three-dimensional space - but also because it is mathematically fallacious to assume that the exponent may vary within a wide range. There have been several critisizing papers on this subject, of which two are cited here.

Professor ir L.H.J. Angenot, of the University of Technology of Delft, has already shown in 1961 (Ref. 4.5) that the gravity model is not satisfactory because it cannot be applied for very short distances (since then the attraction force tends to infinity, which is clearly contrary to everyday experience) and suggests that another distance formula, in the form of -

$$y = \frac{c}{e^{x^2}}$$ may solve the difficulty. This formula not only follows actual patterns within medium distances, but even when the distance approaches zero the attraction force tends to approach a constant value which may be calibrated by the value of 'c'.

In 1961 J.C. Tanner, then of the Road Research Laboratory, showed by mathematical reasoning that the classical distance formula cannot satisfy both extreme cases, of short and long distances, and thus cannot truly represent traffic patterns in towns and in-between towns at the same time - Ref. 4.6. Moreover, if the law is to be acceptable for traffic within a town, the exponent must be less than 3, and probably even somewhat less than 2, while for traffic between towns (for a theoretical case where towns are uniformly distributed) the exponent must be greater than 3.

As can be seen, much effort has been expended to overcome this difficulty of finding an appropriate function for distance. Since it is not the aim of this thesis to fully analyze existing or proposed models, the reader may find summarizing discussions on this subject in many papers, such as 'Description and Shortcomings of some Urban Road Traffic Models' by D.B. Fairthorne (Ref. 4.7), or 'A Comparative Evaluation of Trip Distribution Procedures' by K.E. Heanue and C.E. Pyers, of the Bureau of Public Roads, U.S.A. (General Ref. B.2).

But, just as a footnote, two other traffic models may be mentioned:- The 'Interactance Model', for example, is a development of the gravity model, where 'Friction Factors', which are dependent on travel-times for each trip-purpose within the range of observations, are used instead of physical distance, thus bypassing the problem of defining the exponent of distance or time. On the other hand, the 'Intervening Opportunities Model', as another example, neatly avoids alltogether the problem of defining a physical distance by treating the number of opportunities lying between two points as a measure of the distance separating them.

Coming back to the models used in the social sciences, it appears that the most widely used concept is that of - Demographic Potential, which is a 'scalar' quantity, contrary to the Demographic Force which is a 'vectorial' quantity.

Thus, the knowledge of the number of people, or any other socio-economic measure, and their distances apart, are at once necessary and fully sufficient for the computation of potentials and the ultimate plotting of lines of equipotential on a map.

Moreover, the scalar potential formula, where the exponent of distance is 1, is mathematically less sensitive to probable fluctuations of the exponent than in the Force formula. Not only this, but the potential field represents the total sum of influences exerted by each separate unit on all others, while the Force is an individual and specific case between two defined points within the field. (In classical Mechanics, the Force exerted on unit mass at any point is the space-derivative of the potential at that point).

Thus, the potential field has always been more applicable for a clear, visual, presentation of the interacting influences within an area.

It is of interest to note that traffic models are essentially based on a matrix of individual trips derived from Origin and Destination surveys. In other words, the method of collecting the basic traffic data has not only influenced but ultimatively determined the form of the model to be used, which then has to be calibrated by the collected data.

However, whatever vectorial traffic model is being used for distributing the trips between zones, the final result is always the volumes of traffic assigned to the networks or, in other words, the Kilometrage distribution on the networks. That means a scalar measure for evaluating alternative plans of road networks by the volume-capacity criterion. If, on the other hand, a scalar model could be used from the begininng, much effort, time and money would be saved, from the initial stage of data collection and up to the model calibration and application.

It is not surprizing, therefore, that several researchers have tried to develop such scalar traffic models, based on the potential field concept.

Noteable work has been done by Robert T. Howe, who already in 1959 proposed, in his doctorate thesis (Ref. 4.8) a technique by which an origin-destination survey may be synthesized by applying electrostatic field concepts, including that of potential fields. Although the results were not conclusive at that time, the basic approach is noteworthy and merits an additional try, even if by a somewhat different technique. This may be considered quite urgent now, when traffic models of the most refined sophistication have thrust aside more simple and straightforward techniques.

A second scalar example, and a most interesting one, was developed in Holland in 1964 by ir. 't Hart with the collaboration of ir. H.M. Goudappel and Alan Black (Ref. 4.9).

A central idea of the method is the concept of 'Performance' as a measure of the amount of traffic expressed in person-kilometers per unit of time. The 'Density Performance' is, then, the amount of person-Kilometers per square kilometer per hour.

Based on field surveys, the model developed relates person trip production, by private or public transport, to land-uses, and by the addition of the distance behaviour of trips, inter-district relations can then be simulated with the use of a computer. The authors describe the basic idea of the traffic distribution in the following way:-

> "The trips starting in one district form a 'Hill' of traffic performance which spreads out over the whole city. All these hills for all the districts overlap each other and form a 'Mountain' of traffic performance for the whole city, with the peak at the center. This mountain of traffic performance is the output of the above-mentioned computer program. With these performance data, one can analyze the direct interaction of land use and traffic".

It is of particular interest to note the above description of 'Traffic Performance' by Hills and Mountains, is quite similar to a map of a potential field, although measured in this case by the 'Density Performance'.

It is one of the aims of this thesis, therefore, to investigate the possibilty of again using the concept of Potential Fields for synthesizing traffic patterns in an urban area with sufficient accuracy for a micro first-approximation evaluation.

Refering back to the work done by Stewart, he did not limit himself to the concept of potential fields, but has also shown that many more conclusions may be drawn from such fields as, for example, the 'Gradient' of the field:- The gradient is the rate of change of potential with distance. Thus, if a constant contour interval is maintained throughout a potential map, the gradient of potential is inversely as the spacing of the contours. Whereas potential is a scalar quantity, gradient is a vector directed at right angles to the equipotential contour at any place. Thus, the unit of gradient has the dimensions of persons per kilometer squared. Since the potential of population, for example, has the dimension of the number of people per unit distance, it can mathematical be shown that the unit of gradient and the unit of density have the same dimensions. (Ref. 4.11).

The conclusion that gradient and potential are mathematically interrelated has been tested by Stewart with empirical studies. Such a study for the United Kingdom, for instance, has shown that the rural population density is found to vary as the square of the potential. (Ref. 4.11).

After such a cursory presentation of the vast amount of research done, and studies published, it is time to come back to the practical application of concepts and ideas, and test the hypothesis that potential fields of basic area parameters may usefully be applied in transportation analysis.

3. An Example of Potential Fields.

Already in 1963 the author of this report computed several potential fields of population and vehicles for Israel and compared them with the volumes counted along the major interurban highways. The analysis was based on the 1961 National Survey - for 2 million inhabitants - as well as for projections for 4 million inhabitants. (At the begining of 1971 the population of Israel has passed the 3-million mark).

The then manually-computed potential fields have shown a surprizing correspondence with the actual volumes. Moreover, the ridges of the computed potential fields have also shown a remarkable correspondence with the network of interurban major highways; - the 1961 fields with the then exisiting network, and the projected fields with the planned network.

Since the two-dimensional maps of the potential fields of Israel are too large and complicated for detailed presentation in this report, a more simple example, which was the first preliminary examination of the basic concept in 1963, is presented here, along a one-dimensional cross-section of the major towns in Israel, from Jerusalem in the east, through Tel-Aviv in the west, and up to Haifa in the north, as presented in Figure 4.1.

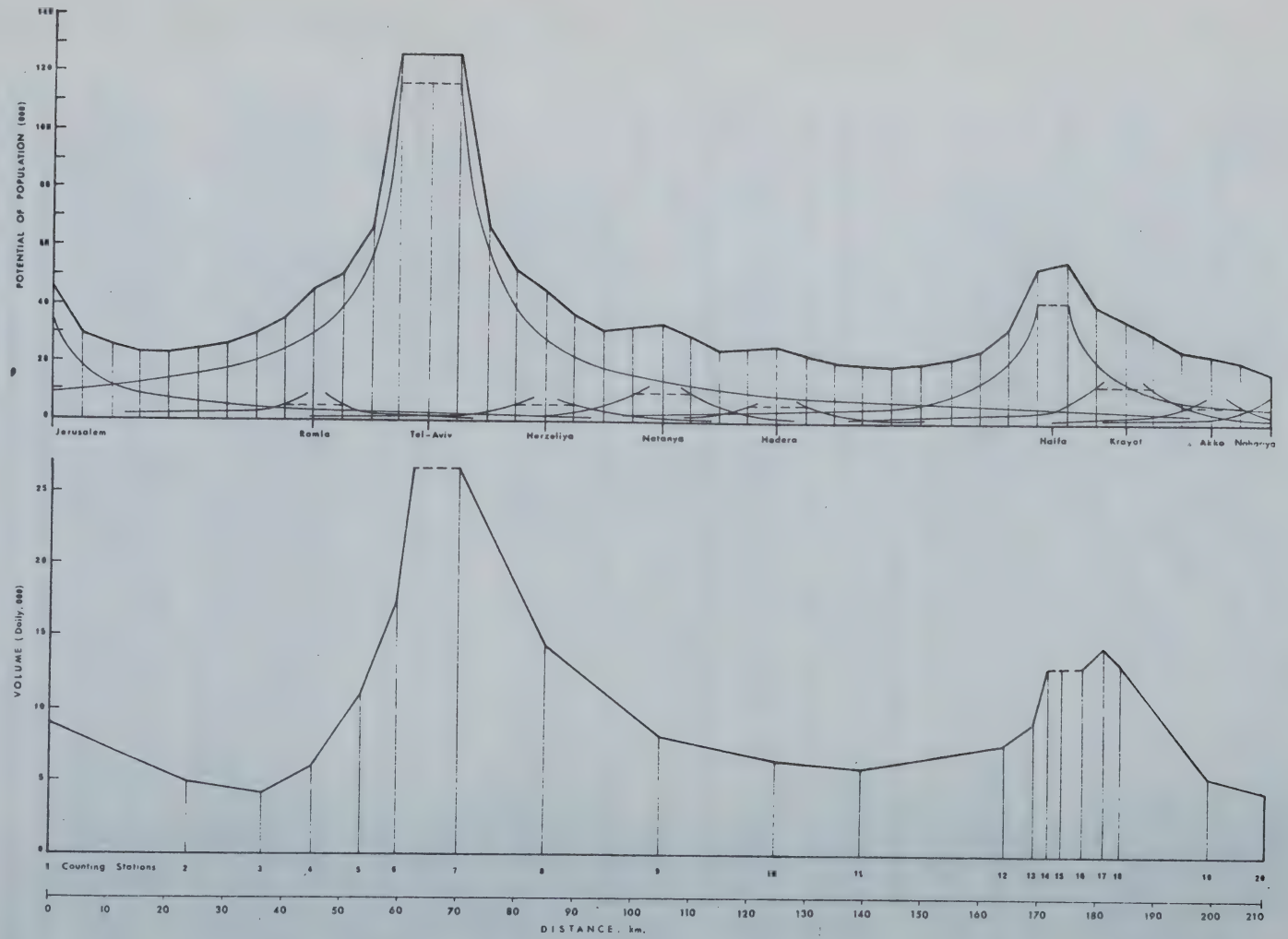
This cross-section of population potential is compared with the 1961 volumes of traffic counted along the interurban highways connecting these towns.

It should be noted, however, that since the volumes have been counted at that period by a limited number of mechanical counters, which were periodically moved from site to site, the volumes shown in the figure represent different months of the year and are, therefore, subject to seasonal variations.

In spite of this limitation, the two curves show a strong similarity between them. (An even better correspondence was found when the volumes were compared with the potential field of vehicles registered in the towns along the cross-section).

A further analysis, with the full two-dimensional maps of potential fields for 1961, then corroborated the assumption that volumes of traffic between centers of population may be represented by the interaction of the population, as presented by their potential fields, with a sufficient accuracy for a first-approximation relative evaluation.

However, it was felt at that time that a more conclusive test, especially for urban traffic, still had to be conducted. That is why the author had to wait for such a test until the begining of 1969, only after he presented to the Municipality of Tel-Aviv - Yafo the report on the 'Tel-Aviv Yafo Transportation Master Plan'. This comprehensive transportation study, which had been based on the 'Interactance Traffic Model' could then supply the necessary data for such a test, as detailed in the following paragraph.


POTENTIAL OF POPULATION (000)
Jerusalem
Ramla
Tel-Aviv
Herzeliya
Netanya
Hadera
Haifa
Krayot
Akko
VOLUME (Daily, 000)
1 Counting Stations 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200 210
DISTANCE, km.

CROSS – SECTIONS OF POPULATION POTENTIAL AND VOLUMES ALONG ISRAEL – 1961

4. Potential Fields of Population and Transportation Parameters.

(1) This paragraph is devoted to the examination of the degree of similarity between potential fields of various area parameters and the traffic volumes.

The hypothesis is that there is a similar trend between the rate of change of volumes from the center outwards and the rate of change of the potential field of a characteristic parameter of that area.

The examination was carried out mostly for the Tel-Aviv metropolitan area, since not only were the comprehensive and detailed information of the transportation study for that area readily available to the author, but also because the study had included several somplete rings of screen-lines around the center where the traffic volumes were counted.

The screen-lines have been planned in such a way so that five major areas could be defined within them, as presented in Fig. 4.2, namely:- (1) Center - including the CBD; (2) Area 1 - including Tel-Aviv proper but excluding the northern and eastern suburbs; (3) Area 1 + 4 - Tel-Aviv proper plus the eastern suburb; (4) Metropolitan proper - approximately half the area with most of the population; and (5) Cordon - around the complete study area.

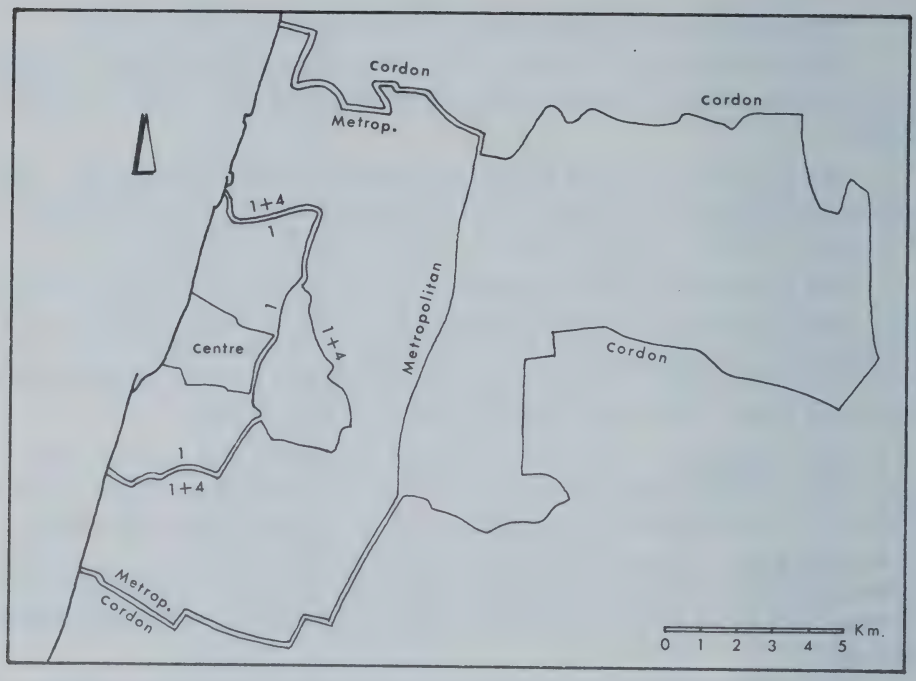
The classified traffic volumes for base-year 1965 were counted at all roads crossing the borders of these areas for 18 hours per average day (06:00 - 24:00) and in each direction separately.

At this stage the volumes to be considered for comparison purposes have to be defined. The first definition includes all types of vehicles counted at the screen-lined in both directions, as presented in Tab. 4.1 and in Fig. 4.3, as a function of the average screen-line distance from the CBD.

The second definition includes 4-wheel vehicles only, excluding 2-3 wheel vehicles, and the volumes are detailed in Tab. 4.2 and Fig. 4.3.

The third definition includes volumes of passenger-car plus commercial-vehicles only, since the traffic model which was applied in the Tel-Aviv study produces trips and kilometrage of these types only. (Public transport trips and kilometrage were treated by a separate model). The volumes thus defined are presented in Tab. 4.3 and in Fig. 4.3.

Table 4.3 and Fig. 4.3 present also the target-year volumes for the same screen-lines, as derived from the application of the assignment model of the Tel-Aviv study, for passenger-cars plus commercial-vehicles. Two curves are shown, one expressing the projected 1985 volumes on the 1965 base-year network, while the other expressing the projected 1985 volumes on the recommended network planned for 1985.



TEL-AVIV AREA SCREEN-LINES

Fig. 4.2

Table 4.1

Screen-Line Total Volumes

Tel-Aviv 1965, both directions, 18 hours.

Reference: Ref. 1.3.

Screen	Average Distance from Center, km.	Total Volume
Center	1.4	348,819
Area 1	2.6	229,993
Area 1 + 4	3.2	201,981
Metrop.	7.1	105,785
Cordon	9.8	75,437

Table 4.2

Screen-Line 4-Wheel Volumes

Both directions, 18 hr.

Screen	Average Distance From Center, km.	4-Wheel Volume	Percentage of 2-3 Wheel Veh. from Total
Center	1.4	262,072	24.9
Area 1	2.6	185,788	19.2
Area 1 + 4	3.2	169,946	16.4
Metrop.	7.1	95,015	10.2
Cordon	9.8	69,692	7.6

Table 4.3

Screen-Line. Pass. Cars + Comm. Veh. Volumes

18 hours

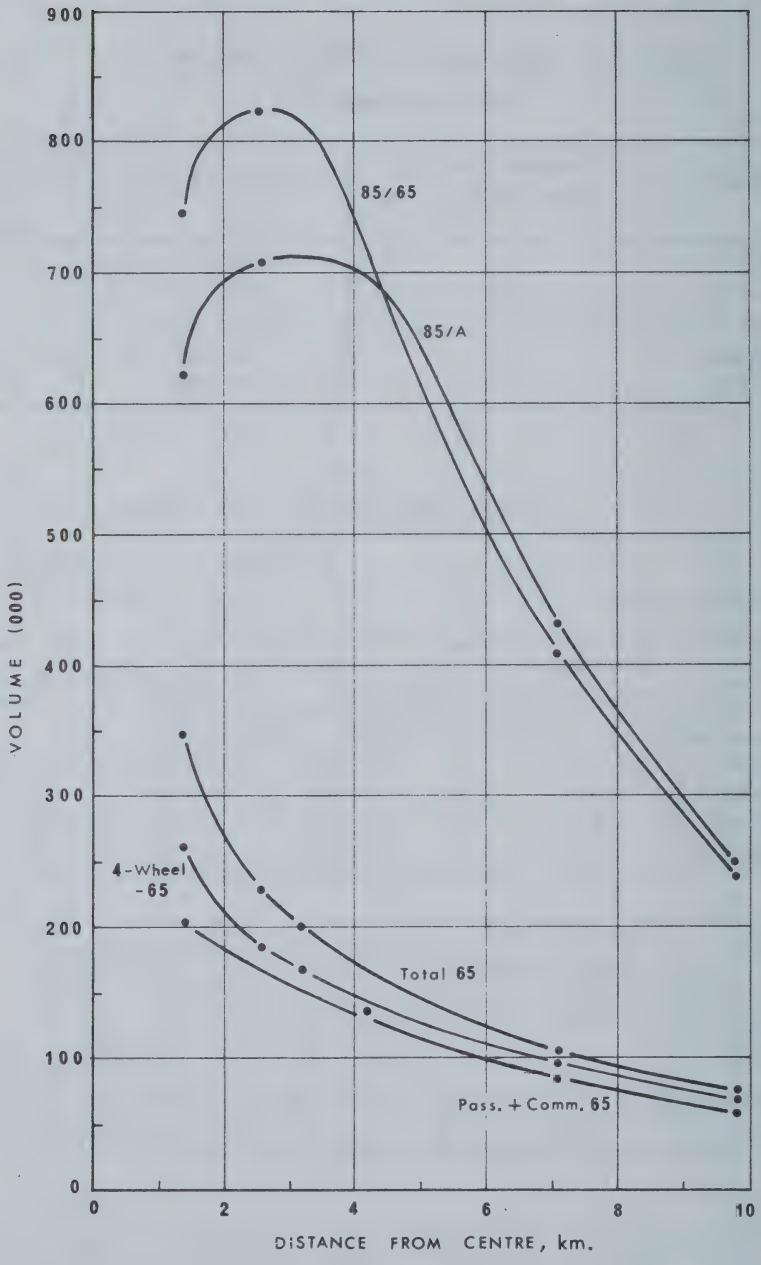
1965

Screen	Average Dis. from Center	v o l u m e		
		Towards Center	From Center	Total
Center	1.4	100,852	103,087	203,939
Tel-Aviv	4.2	69,426	66,536	135,962
Metrop.	7.1	42,622	41,560	84,182
Cordon	9.8	29,727	28,932	58,659

1985

Screen	Average Dis. from Center	Total 85/65	Total 85/A
Center	1.4	748,664	622,658
Screen 1	2.6	824,282	707,968
Metrop.	7.1	409,429	433,801
Cordon	9.8	239,336	249,124

While looking at the three base-year volumes in Fig. 4.3, a few points are noteworthy:- The total volumes show a strong and prominently accelerated increase towards the center of the area; the 4-whell vehicle volumes still show a strong increase towards the center, though to a lesser degree; the passenger car plus commercial vehicle volumes entering the ring-areas show, on the other hand, nearly a constant increase towards the center.



SCREEN-LINE VOLUMES

Fig. 4.3

As will be shown later-on, the last curve is the most important one for the 'IN' procedure computations.

(2) When a comparison is made between the base-year and the target-year volumes crossing the screen-lines an interesting phenomenon should be pointed out. As the volumes increase from 1965 to 1985, the shape of their curves change in a characteristic way. This change may be explained in the following way:- With the development of a metropolitan area the population and their motorization levels increase differentially; as a result the volumes at the center continue to increase, but to a relatively lesser degree than at the surrounding rings; when the volumes at the center reach the network's capacity, there is an ever-increasing over-flow of traffic around the center; since the road-areas increase proportionally with the increasing areas of the rings around the center, they are able to absorb higher levels of volumes than the center; thus the characteristic shape of the volume cross-section at the screen-lines around the center has to change as well, representing the over-flow of traffic to adjacent areas around the center.

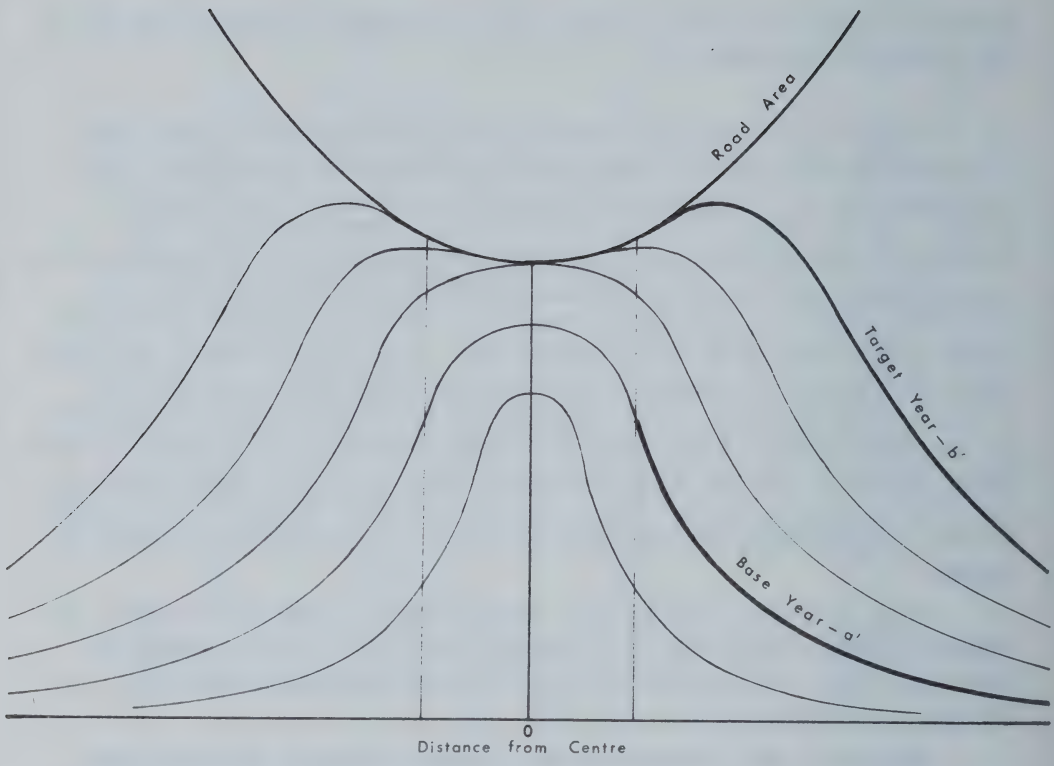
This process, which is well known in many towns in the world, is depicted graphically in Fig. 4.4, showing how curve 'a' may change its form into curve 'b' (equivalent to 1965 and 1985 volumes respectively) by the ever-increasing volumes of traffic.

Moreover, the introduction of a Freeway network, in most cases some way from and around the center, accelerates this tendency even more so, by draining the center from a part of the through-traffic and transfering it to adjacent areas. This process may be seen clearly in the volume curves 1985/65 and 1985/A in Fig. 4.4, where the recommended plan 'A' includes a network of Freeways.

The basic process of differential growth in a metropolitan area, and its effects on many characteristic area parameters, are well known all over the world. Fig. 4.5 presents just one such example, that for the population density as a function of distance from the CBD of Tel-Aviv for the years 1965 - 1985 - 2000, and the same relative pattern may be recognized again.

(3) This example brings us back to the basic question, of whether a characteristic parameter of a metropolitan area may represent the volumes as a function of distance from the center of the area.

Thus, potential fields of many such parameters have been computed for the Tel-Aviv metropolitan area for base and target years. The fields have been computed on the basis of Eq. 4.5, for the spatial distribution of various parameters, such as population, employment, passenger-cars, land uses, etc., as well as combinations of such parameters. The computations



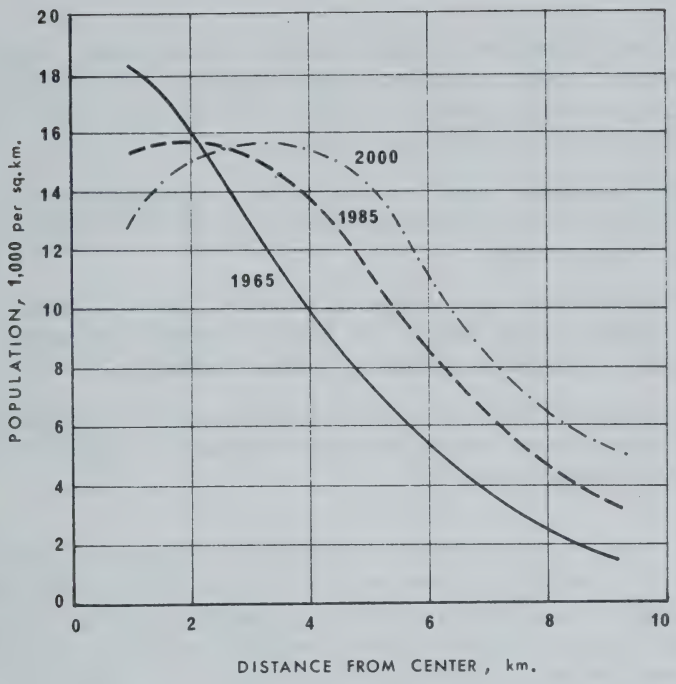
VOLUME PATTERNS TOWARDS THE CENTER

Fig. 4.4

were carried out by a specially developed computer program. The value of 'G' in Eq. 4.5 was considered as unity, while the value of 'r_{ii}' namely for P_i at zone 'i', was considered as half the average radius. The values of the parameter 'P'', as well as the resultant potential field values, are detailed in App. 6 for three parameters.

The three parameters which have finally been chosen for presentation are the basic ones of Vehicles, Employment, and Population.

To enable a comparative evaluation of the various potential fields, the numerical results for the traffic zones of each potential field have then been calculated in percentage, assuming 100 per cent for the sum of potential values in the whole area, as detailed in App. 7 for base and target



POPULATION DENSITY
Tel – Aviv

Fig. 4.5

years. The results, in per cent, are presented in a graphical form in Fig. 4.6 to Fig. 4.11.

This method of relative presentation of percentages of the values has been chosen with the purpose of expressing the relative change in the intensity of each zone to the others in the area between base and target years. (The same zones have been used or the two periods of time).

Although the potential fields presented in Fig. 4.6 to Fig. 4.11 are an intermediate stage only in the analysis, they show some interesting patterns which merit pointing out:-

(1) All of them show the same principle pattern, with a major peak at - or near - the center of the CBD;

(2) A comparison between base-year and target-year fields show clearly the general trend of a differential growth in the area, where the suburbs take an increasing share of the total growth;

(3) While Tel-Aviv remains the focal point of Employment, even for the target-year, new prominent peaks appear for other parameters, such as for population (and for all other parameters which are closely related to the population distribution);

(4) The ridges emanating from the central peak correspond very closely with the major exes of Arterials connecting Tel-Aviv with the satelite towns and external areas.

The last phenomenon is of a special interest, since although the potential field is scalar in its nature, its ridge patterns correspond very closely with the directional axes of major traffic corridors.

This is an expected result, since the major axes of Arterials in an urban area pass along highly densed population areas, thus the two should be closely related to each other.

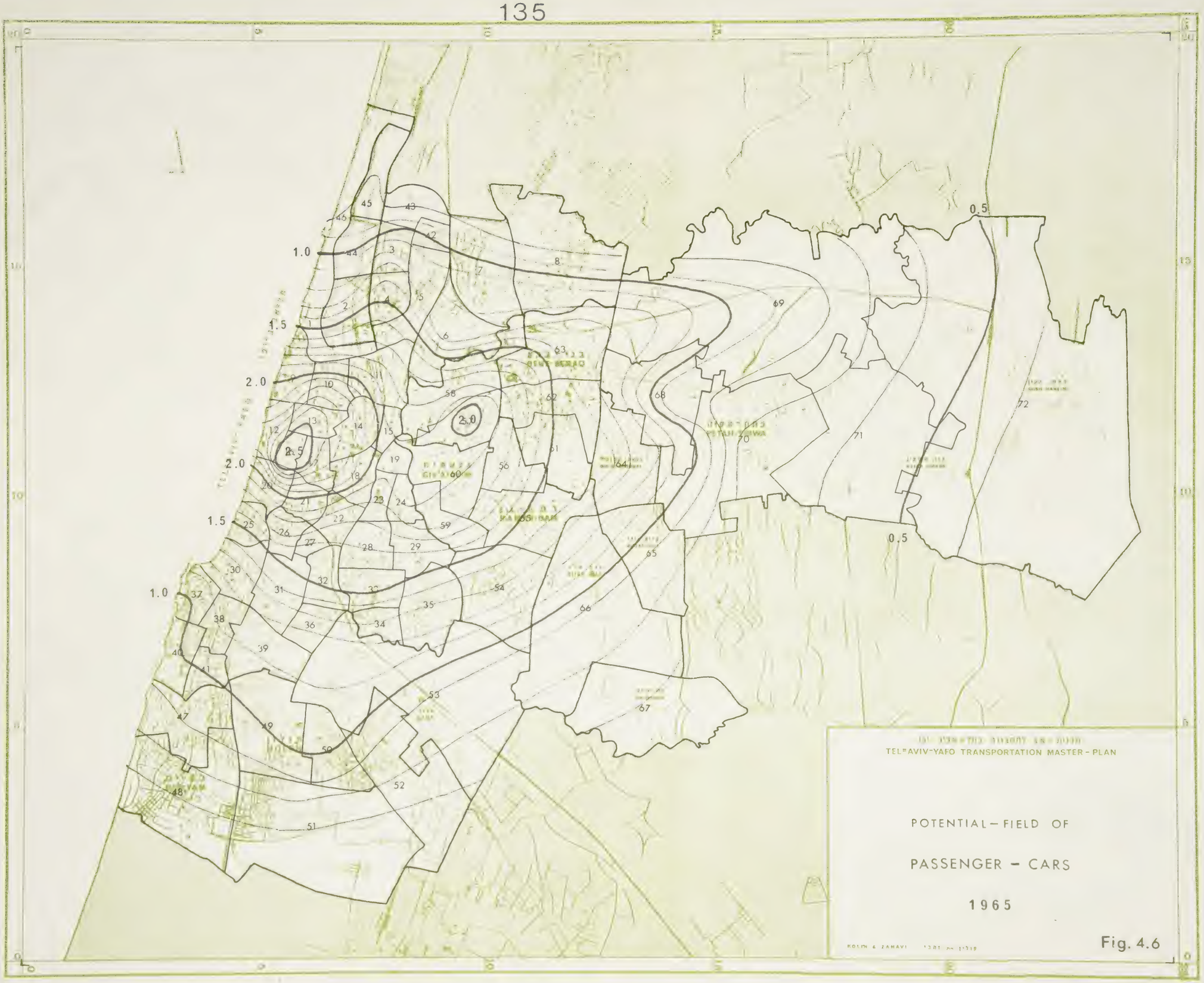
In other words, the potential fields may also represent, in a general way, the demand for radial corridors of roads in the area. (The same patterns were found for the potential field of population for the whole of Israel, corresponding very closely with the national corridors of highways, as has already been mentioned earlier). This conclusion refers, of course, mostly to Arterials, since the urban Freeway network may not necessarily adhere to these direct corridors but rather be parallel to them at some distance away, thus by-passing highly densed population corridors.

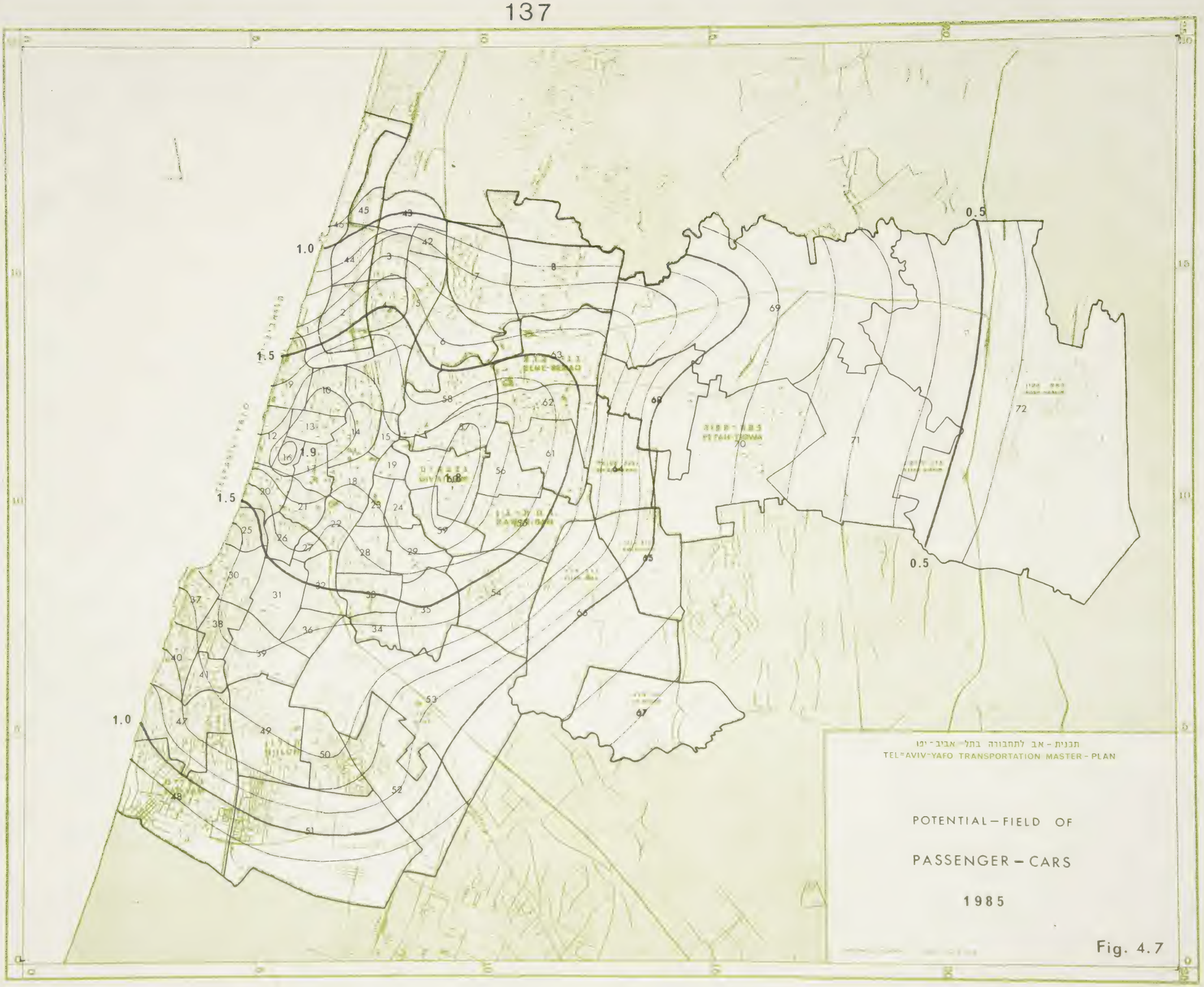
(4) In the next stage of analysis an average cross-section of each potential field was computed, relative to the CBD, as presented in Fig. 4.12 to Fig. 4.14.

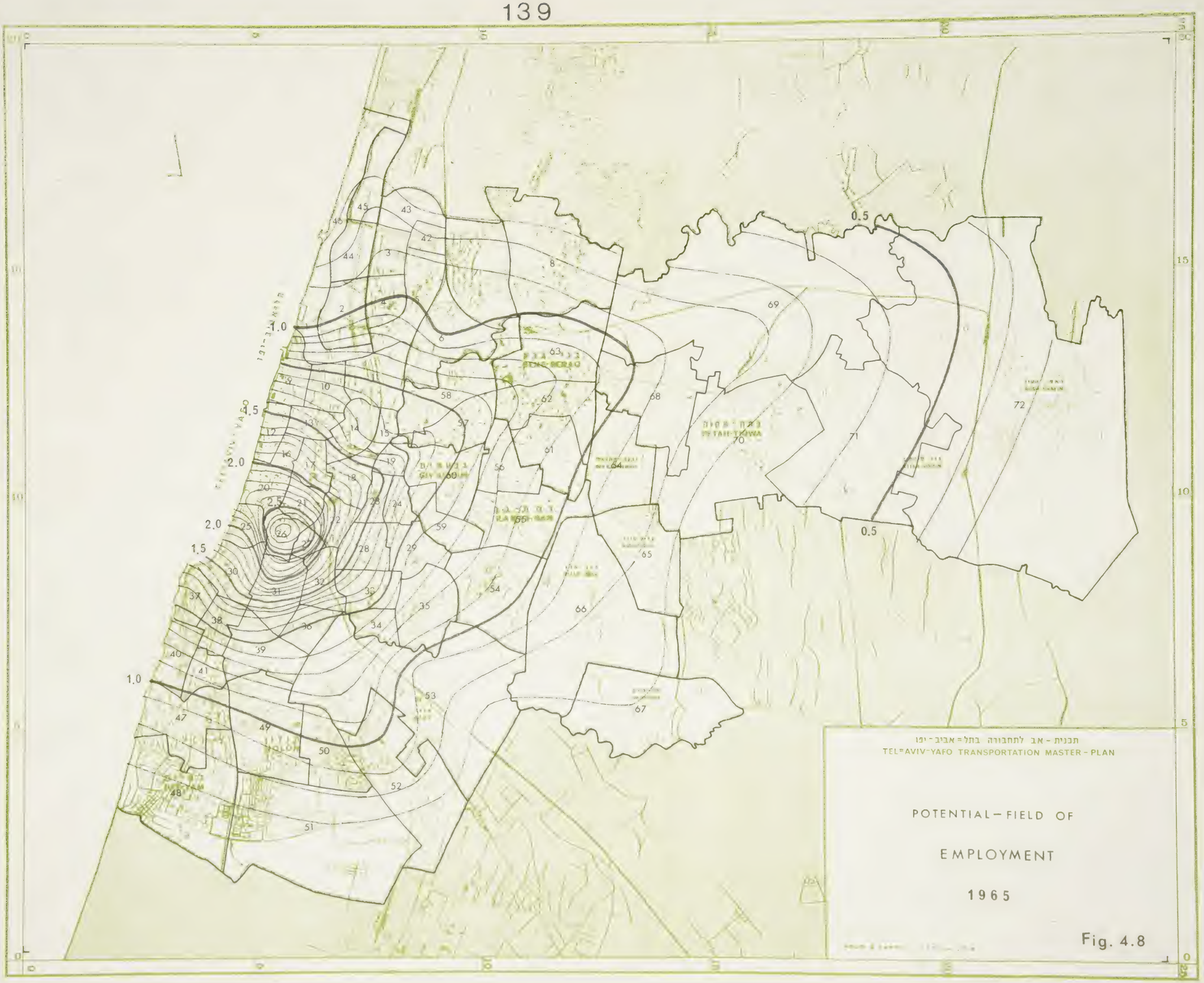
These figures show, then, the rate-of-change of the potential fields as a function of distance from the center of the CBD. To enable a comparison between the various fields, they have been presented in a relative form, where the value nearest to the border of the CBD had been considered as 100 per cent (Appendix 7).

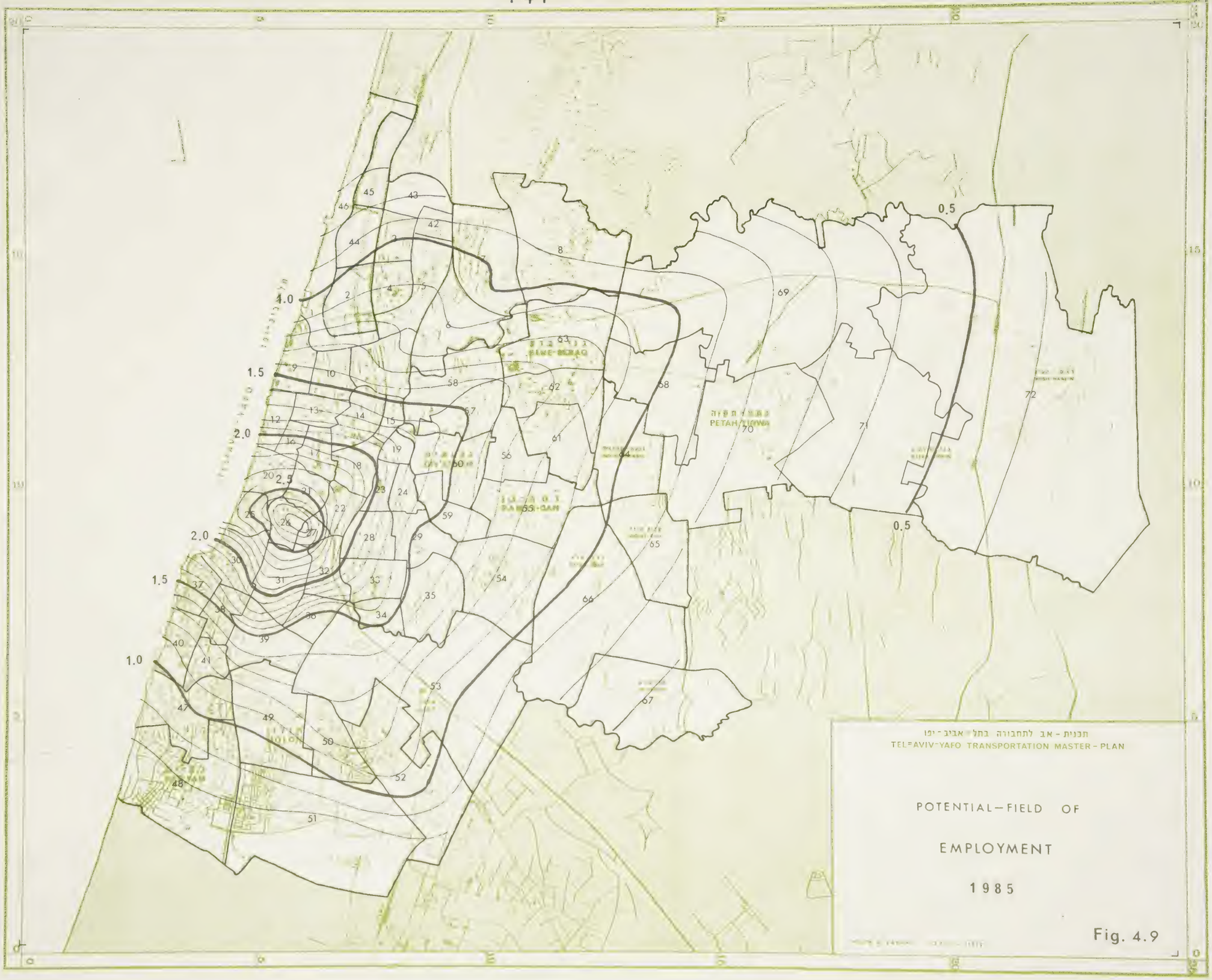
These cross-section curves of potential fields have then been compared with the cross-section curves of the traffic volumes at the screen-lines, for base and target years.

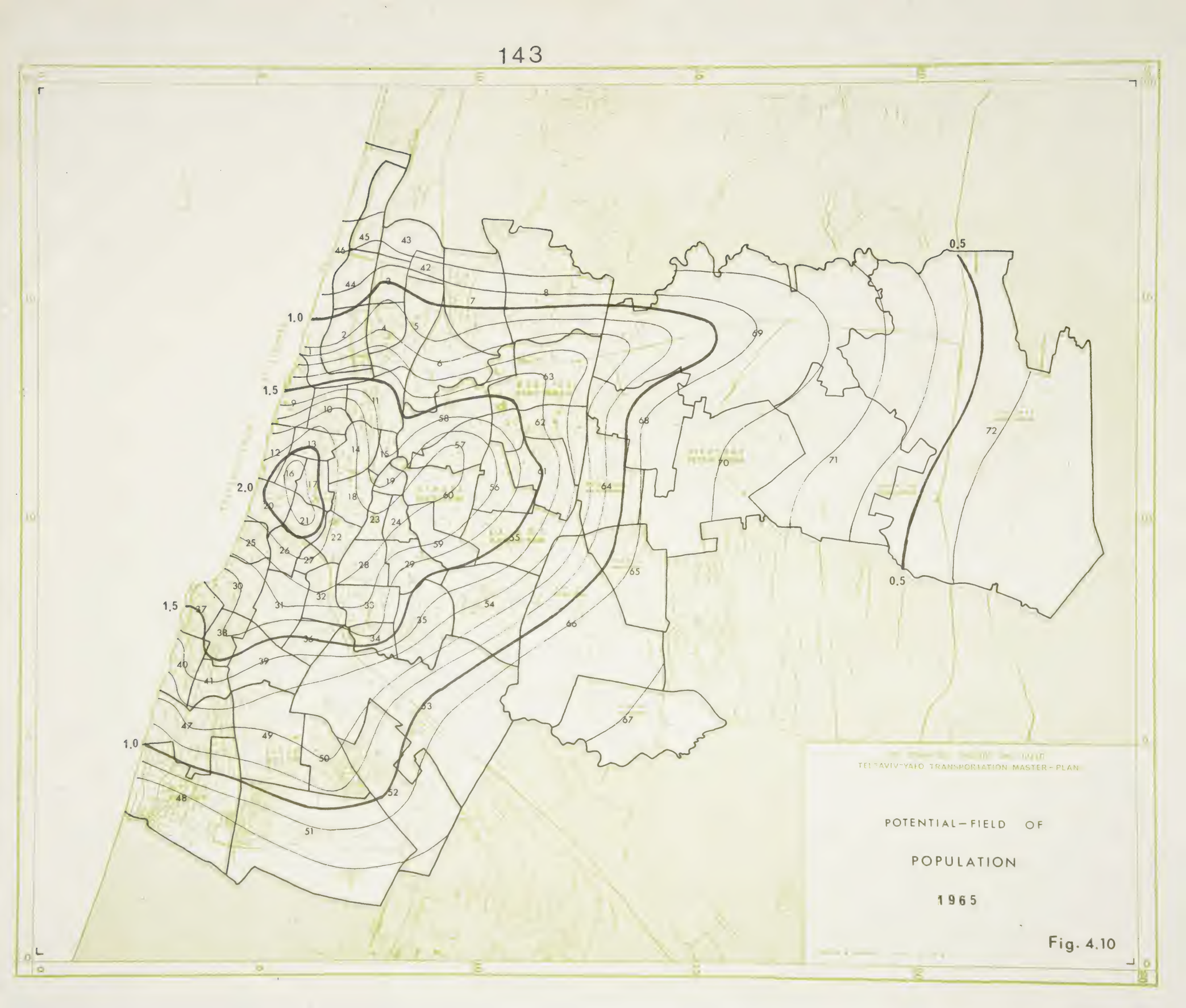
At this stage it may be mentioned that the best correlation found had been that for vehicle attracted trip-ends versus traffic volumes, but since only direct parameters characterizing the area are to be considered (with no O-D matrices), the final presentation had been restricted to the three basic parameters shown.

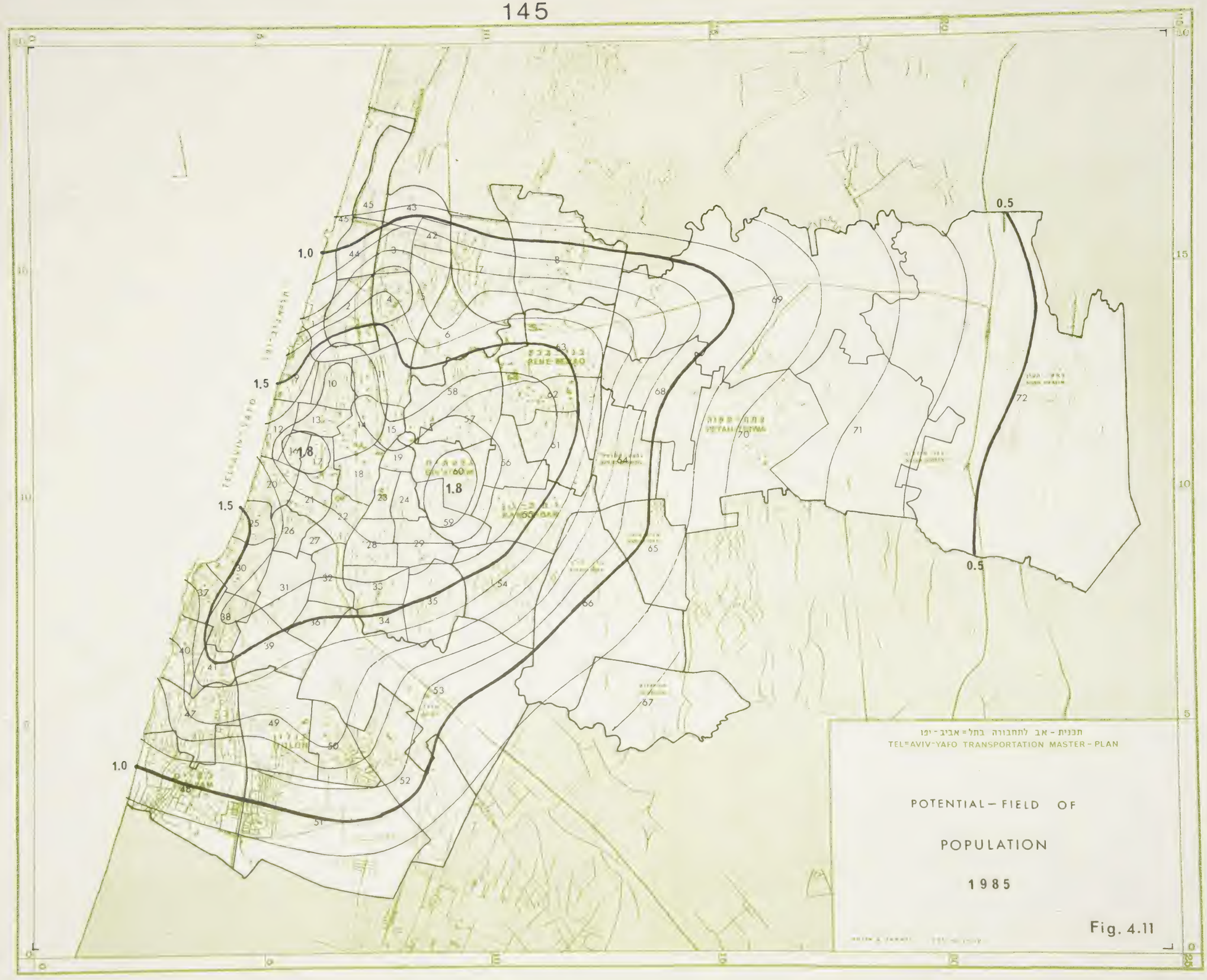

1.0
1.5
2.0
2.5
2.0
1.5
1.0
0.5
0.5
TEL-AVIV-YAFO TRANSPORTATION MASTER-PLAN
POTENTIAL – FIELD OF
PASSENGER – CARS
1965
Fig. 4.6

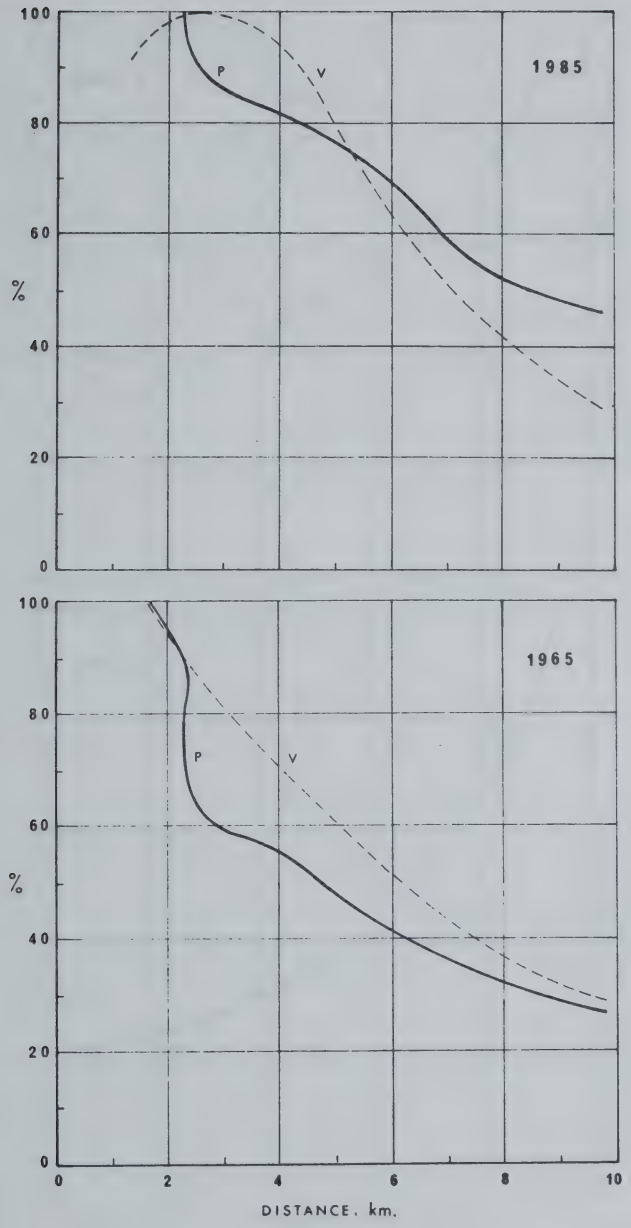

1.0
1.5
1.9
1.8
1.5
1.0
0.5
0.5
תכנית - אב לתחבורה בתל - אביב - יפו
TEL-AVIV-YAFO TRANSPORTATION MASTER - PLAN
POTENTIAL – FIELD OF
PASSENGER – CARS
1985
Fig. 4.7


0.5
1.0
1.5
2.0
2.5
תבנית - אב לתחבורה בתל-אביב-יפו
TEL-AVIV-YAFO TRANSPORTATION MASTER - PLAN
POTENTIAL - FIELD OF
EMPLOYMENT
1965
Fig. 4.8


4.0
1.5
2.0
2.5
2.0
1.5
1.0
0.5
0.5
PETAH/TIQWA
תכנית - אב לתחבורה בתל - אביב - יפו
TEL-AVIV-YAFO TRANSPORTATION MASTER - PLAN
POTENTIAL - FIELD OF
EMPLOYMENT
1985
Fig. 4.9


0.5
1.0
1.5
2.0
1.5
1.0
0.5
TEL AVIV-YAFO TRANSPORTATION MASTER-PLAN
POTENTIAL-FIELD OF
POPULATION
1965
Fig. 4.10

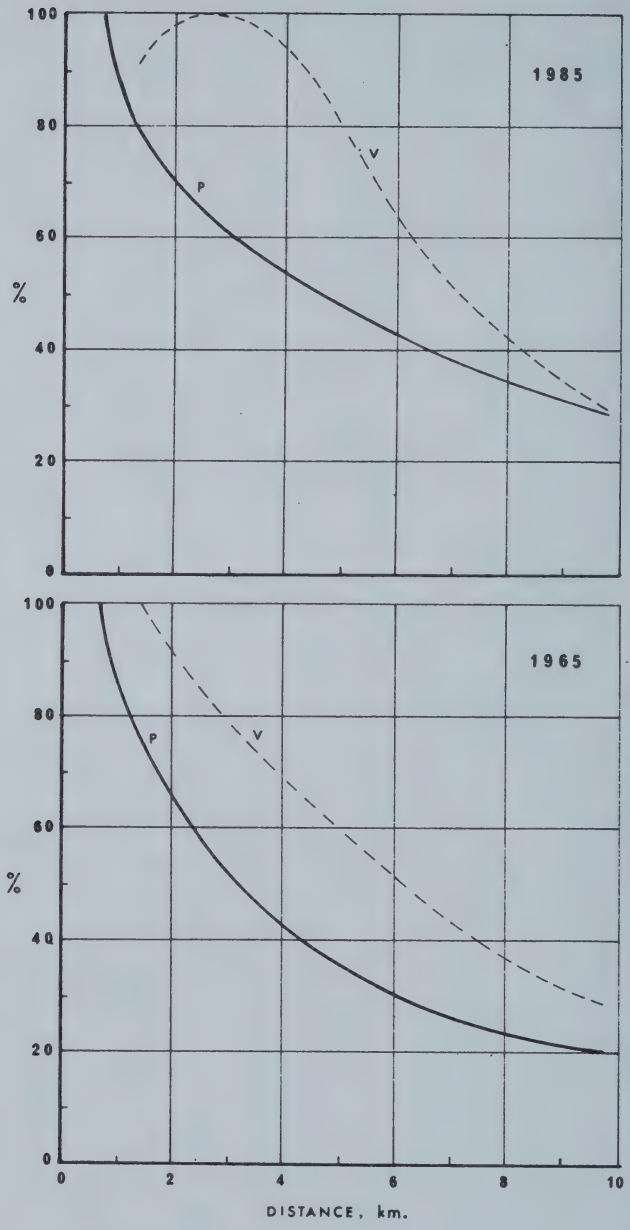

1.0
1.5
1.8
1.8
1.5
1.0
0.5
0.5
תכנית - אב לתחבורה בתל=אביב - יפו
TEL=AVIV-YAFO TRANSPORTATION MASTER - PLAN
POTENTIAL - FIELD OF
POPULATION
1985
Fig. 4.11



POTENTIAL-FIELD CROSS-SECTIONS

Pass. Cars vs. Volumes

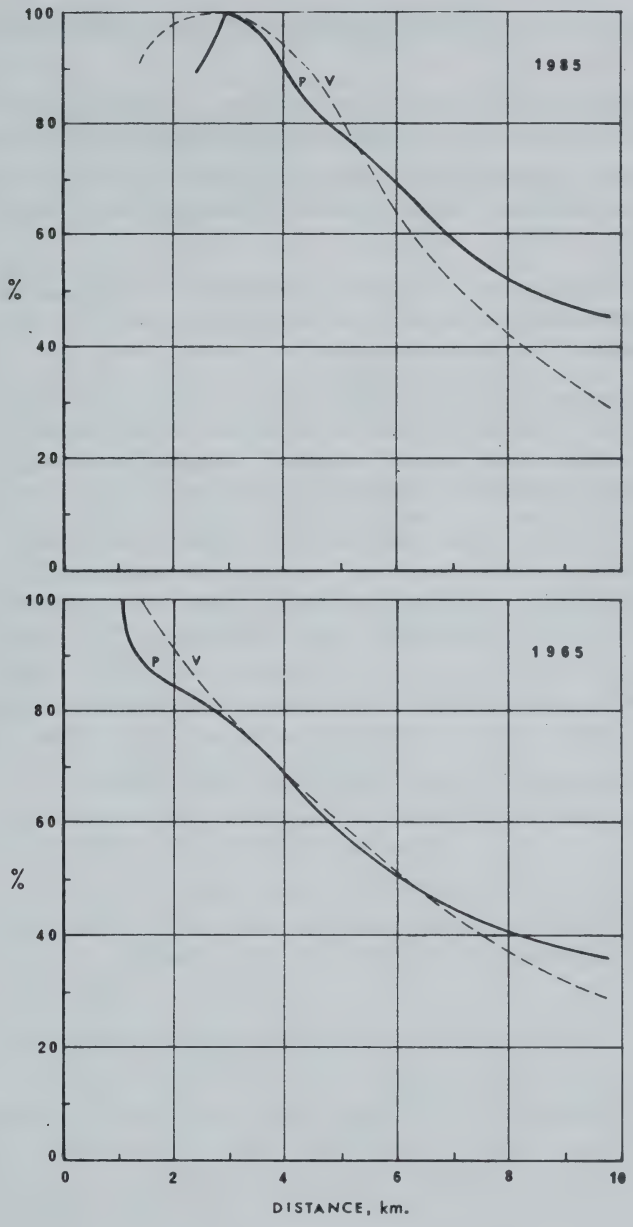
Fig. 4.12



POTENTIAL-FIELD CROSS-SECTIONS

Employment vs. Volumes

Fig. 4.13



POTENTIAL-FIELD CROSS-SECTIONS

Population vs. Volumes

Fig. 4.14

In regard to these three parameters, the following conclusions may be drawn:-

(a) The correlation for base-year vehicles vs. total volumes seems to be quite a good one, although not satisfactory for the target-year;

(b) The correlation for base-year employment vs. total volumes seems to be the best one, although far from satisfactory for the target-year;

(c) The correlation for base-year population vs. volumes (of passenger cars plus commercial vehicles) seems to be a good one, and quite satisfactory for the target-year.

By considering again the three parameters vs. volumes, it may be concluded that the best one of the three is that of population versus passenger cars plus commercial vehicle volumes. Population is also the most simple and direct parameter available for any metropolitan area.

(5) The analysis up to now had been an intermediate stage only and a most important link is still missing, namely the relationship between the volume and the kilometrage distribution. In other words, because the major factor in the synthesis procedure is the Kilometrage 'K' - and not the volume - the crucial question now is whether the Kilometrage may be distributed in the area according to the volume distribution, or any other such parameter.

This subject will be discussed in the next chapter.

* * *

CHAPTER 5: TRAFFIC ON THE ROAD NETWORK.

1. Introduction.

In the first three chapters a procedure was developed by which many travel parameters could be synthesized easily and rapidly, such as the total vehicle trips and Kilometrage in an urban area; the proportions of the Kilometrage assigned to the various categories of roads; the total lengths of the Freeways, Arterials and Locals needed to satisfy the travel demands, as well as their spacings.

However, all those parameters of travel and components of networks were total for the whole area. Thus, an additional procedure has been developed in chapter 4, by which the gradient of volumes in an urban area may be synthesized by the gradient of the potential field of population.

The first paragraph in this chapter will cover, therefore, several methods by which the total Kilometrage may be distributed over the area, if by the volume gradient, and if by additional and independent methods.

The second paragraph will introduce a new and important parameter into the framework of network analysis, namely that of the Speed, and it will be shown how this parameter may assist in defining quantitatively the service level of a network.

The third paragraph will continue to develope the 'IN' procedure, and it will be shown how the travel parameters in an urban area may be fully synthesized by applying this procedure.

The fourth paragraph will present examples of the way how to apply the synthesis procedure to practical conditions.

The fifth and last paragraph in this chapter will show how the synthesis procedure may be used for a rapid economic evaluation of different alternatives of road network, with the purpose of assessing their efficiencies by economic criteria.

2. The distribution of Kilometrage in an urban area.

This paragraph will present several short and simple methods by which the travel intesity in an urban area may be distributed and evaluated. The following methods are by no means the only ones and they are presented as examples only, showing the wide range of possible techniques that are available to the planner.

(1) The maximum volume that can enter a CBD.

The most critical part of an urban area is the Central Business District (CBD), where not only most of the destinations are concentrated, but where a substantial part of the traffic is a through one, passing through the center with no destinations there.

Moreover, the area of a CBD is relatively small, in most cases not more than 2-3 sq.km. As a result, the number of internal trips, namely those that begin and end within the CBD, is relatively small and can be ignored when compared with the very high volumes of trips that have one or both ends outside the area. For practical purposes, therefore, the traffic capacity of a CBD may be expressed by the volumes that can enter it.

The first question is, therefore, whether there is a method by which the traffic capacity of the center may be defined for volumes as well as for Kilometrage.

Professor R.J. Smeed has already shown that the maximum number of vehicles that can enter an actual CBD is given very roughly by the formula : $N_m = 100\ f\sqrt{A}$, where 'N_m' is the maximum number of passenger-car units (p.c.u.) that can usefully enter per hour, 'f' is the fraction of the area of the CBD devoted to carriageway, and 'A' is the area of the CBD expressed in sq.met.

The development of this formula, as well as defining its numerical values, is as follows (which is somewhat different from the original procedure used by Prof. Smeed):

If we define:-

A - area of the CBD (sq.met.);
f - proportion of that area used for carriageway;
b - proportion of the carriageway used for traffic (excluding lanes used for parking, etc.);
w - average width of lanes (met.);
L - total length of free lanes for traffic (met.);
q_m - maximum volume per lane at peak-hour at optimal speed (vph);
n - number of free lanes entering the area;
N_m - maximum number of vehicles which can enter the area at peak-hour (vph);
N - the number of cars which can enter the area per hour for any value of q;

Then:-

$$L = A\frac{f.b}{w}\ ; \qquad (5.1)$$

$$n = \frac{L}{\sqrt{A}} \text{ (assuming a square area)}; \qquad (5.2)$$

$$N_m = n.q_m = q_m \frac{A.f.b}{w\sqrt{A}} = \left(\frac{q_m.b}{w}\right) f\sqrt{A} \qquad (5.3)$$

The final form of Eq. 5.3 is the same at that of - $N_m = (100)\, f \sqrt{A}$ and it only remains now to compute the numerical value of $(\frac{q_m \cdot b}{w})$

As has already been shown in chapter 1, q_m for a CBD network is about 666 vph at some 10 kph (App.1). Moreover, a careful check of the CBD of Tel-Aviv has shown the following factors:

$f = 0.125; \qquad b = 0.55; \qquad w = 3.50.$

thus:-

$$N_m = (\frac{q_m . b}{w})\, f \sqrt{A} = (\frac{666 \times 0.55}{3.50})\, f \sqrt{A} = 104.5\, f \sqrt{A}; \qquad (5.4)$$

which is in close agreement with the original formula derived by Prof. Smeed. Moreover, by instituting a cordon-count of 'N' in the formula, and using the Speed-Volume relationship in Fig. 1.4 for a CBD road network, the average travel speed for any given CBD may be derived, as well as the 'Utilization Factor' of the network may be defined, as the ratio of - $q/q_m \leqslant 1.00$.

The validity of Eq. 5.4. has been tested by applying actual data from eight towns in the U.K. (Ref. 5.3), as well as from Tel-Aviv for base and target years, as detailed in Tab. 5.1.

The table details the percentage of area devoted to roads in the CBD. Two remarks are here in order: (a) In two cases the percentage had to be assumed since the actual data did not detail it; (b) In the case of Leeds the percentage of 21 seems to be very high in comparison with the other towns, but no explanation is forwarded in the report. It was adjusted, therefore, to conform with the other towns.

The table also includes the counted peak-hour volumes, in p.c.u., entering the cordons (in one direction, towards the center), as well as the computed maximum possible volumes by Eq. 5.4.

It should be noted that for all base-year data the factor 'b' has been assumed to be b = 0.55, as found for the CBD of Tel-Aviv at base-year, while for the target-year 1985 the factor has been assumed to be - b = 0.65, since the recommended traffic plan for Tel-Aviv called for severe restrictions on curb-parking.

The last factor to be computed in the table has been that of the 'Utilization Factor' of the road network, as a ratio between N/N_m. The relationship between this factor and population is presented in Fig. 5.1, which shows a most interesting correlation, namely that for the base-year levels of motorization for the UK towns, a saturation level of the CBD

network is reached at a population of about 200,000 inhabitants. Since no motorization levels have been presented in the original report, it is assumed to be near the level of London at that time, namely about 15-16 per cent.

Tel-Aviv at base-year, on the other hand, is still below the saturation level since its mororization level at the time had been 4.9 only. However, the forecasted level, for the target-year 1985, is 16.4, i.e., within the same level as that for the UK towns at base-year 1965. And indeed, the projected volume for the Tel-Aviv CBD in 1985 has reached saturation level, in accordance with the relationship shown. (Alternatively, for a given constant population the saturation level may be computed by assuming various notorization levels on an increasing scale).

It may be concluded, therefore, that Eq. 5.4 seems to be not only valid for practical applications at base-year conditions, but it also enables to compute the time - or situation - at which the existing network of a town may become saturated.

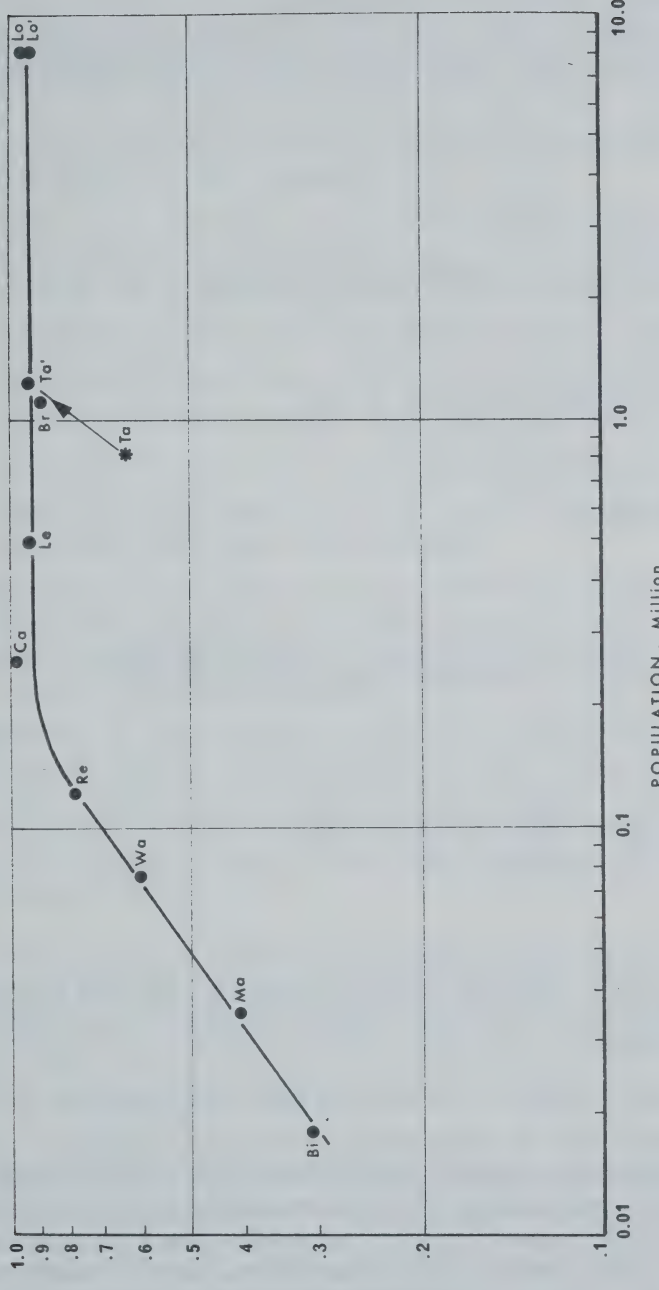
Further camparisons made with the same basic Eq. 5.4 may be found in Ref. 5.1, 5,2.

Table 5.1

Peak-Hour Volumes Entering Central Areas of Towns

Sources: (a) Ref. 5.3
(b) Ref. 1.1

No.	Town	Population (ooo)	Central Area, Sq. Km.	$\sqrt{A}$	f	N	N_m	η
Bi	Bishop's Stortford	18	0.18	0.42	(14)	1,895	6,200	0.31
Ma	Maidenhead	35	0.30	0.55	14	3,265	8,000	0.41
Wa	Watford	76	0.44	0.66	10	4,180	6,830	0.61
Re	Reading	120	0.40	0.63	15	7,660	9,900	0.78
Ca	Cardiff	256	0.85	0.92	12	11,300	11,520	0.98
Le	Leeds	511	1.17	1.08	(15)	15,955	17,000	0.94
Br	Birmingham	1,106	2.38	1.54	15	21,480	24,100	0.89
Lo	London	8,172	32.36	5.68	14	79,660	83,000	0.96
Lo'	London (West End)	8,172	1.68	1.29	(14)	17,720	18,900	0.94
Ta	Tel-Aviv - 1965	817	4.80	2.19	12.5	14,900	23,350	0.64
Ta'	" " - 1985	1,225	4.80	2.19	12.5	31,800	33,900	0.94



UTILISATION FACTOR OF TOWN CENTRES

Fig. 5.1

(2) The Volume - Kilometrage relationship.

The relationship between the volume and the Kilometrage may be found by applying the formula already developed in the previous pages, as follows;-

(a) The volume has already been expressed by Eq. 5.3 as -

$$N = (\frac{q \cdot b}{w}) f \sqrt{A} \quad ;$$

(b) The Kilometrage has already been expressed by Eq. 3.3 as -

$$K = q.L \quad ;$$

(c) Since Eq. 5.1 has expressed 'L' as -

$$L = (\frac{A \cdot b}{w}) f \quad ;$$

(d) It follows that -

$$K = (\frac{q \cdot b}{w}) f A \quad ; \qquad (5.5)$$

(e) Thus, the relationship between the Kilometrage and the Volume may be expressed by the following for - mula -

$$\frac{K}{N} = \frac{(\frac{q.b}{w}) f \ A}{(\frac{q.b}{w}) f \ \sqrt{A}} = \sqrt{A} \quad ; \qquad (5.6)$$

This is a most simplified relationship, which says the total Kilometrage in an area equals the entering volumes multiplied by the distance of travel through the area.

At this stage, however, several additional considerations are in order:-

(1) It is assumed that the Kilometrage produced by internal - internal trips is negligible, thus the total Kilometrage in an area may be expressed by the entering volumes. A sustaining consideration may be found in a new research, not yet published at the time of writing this part of the thesis. ("The effect of zone size on traffic assignments and trip distribution', by J.D. Delaney, K.E. Thompson, and B.R. Wildermuth, submitted for the 1972 Annual Meeting of the Highway Research Board, U.S.A.).

In this research a detailed analysis was carried out on the effect of zone size on the assigned Kilometrage. By a thorough analysis of the Melbourne Metropolitan Transportation Study data, it was found that reducing the number of zones from its initial number of 607 down to only 40 zones had a marked effect on the number of trips, but only a marginal effect on the Kilometrage. In the original words of the authors of this research:-

> "Since trips that begin and end in the same zone are not allocated to the road network in the traffic assignment process, the increase in the proportion of such trips and the amount of travel that they generate was appraised in relation to zone size. It was found that although the number of intra-zonal trips may be substantial, the amount of travel that they generate is small. For the plans tested, intrazonal trips ranged from 10.4 per cent (607 zones) to 38.6 per cent (40 zones) of total trips. However, they accounted for only between 1.2 per cent and 8.9 per cent of the vehicle-miles travelled on the major street system".

Since the Melbourne study area is 1,500 sq.km., it follows that by increasing the area of an average zone from 2.5 sq.km. to 37.5 sq.km., namely by 15 times, resulted in a reduction of only 7.7 per cent of the total Kilometrage.

Therefore, it may be argued that for a first-approximation evaluation of a zone, sector or a ring, within an urban area, its Kilometrage may be expressed by the inter-zonal trips only, while neglecting the intra-zonal trips. In other words, the Kilometrage of such an area may be computed by considering only its entering - and passing - volumes of trips.

(2) It should be noted, however, that since not all the trips which enter an area are through-trips, because some of them terminate there, it should be expected that in most cases the relationship expressing actual conditions would be -

$$\frac{K}{N} \leqslant \sqrt{A} \; ; \qquad (5.7)$$

Prof. Smeed, in his "Traffic Studies and Urban Congestion" (Ref. 1.9) computed the average distance travelled on some imaginary and real road networks, while considering all possible movements, namely internal, cross-cordon and through trips. The results are presented in Fig. 5.2, where the theoretical values are within $0.87\sqrt{A} - 0.97\sqrt{A}$, while the actual values found are within a narrower range

Fig. 2

AVERAGE DISTANCE TRAVELLED ON SOME IMAGINARY AND REAL ROAD NETWORKS

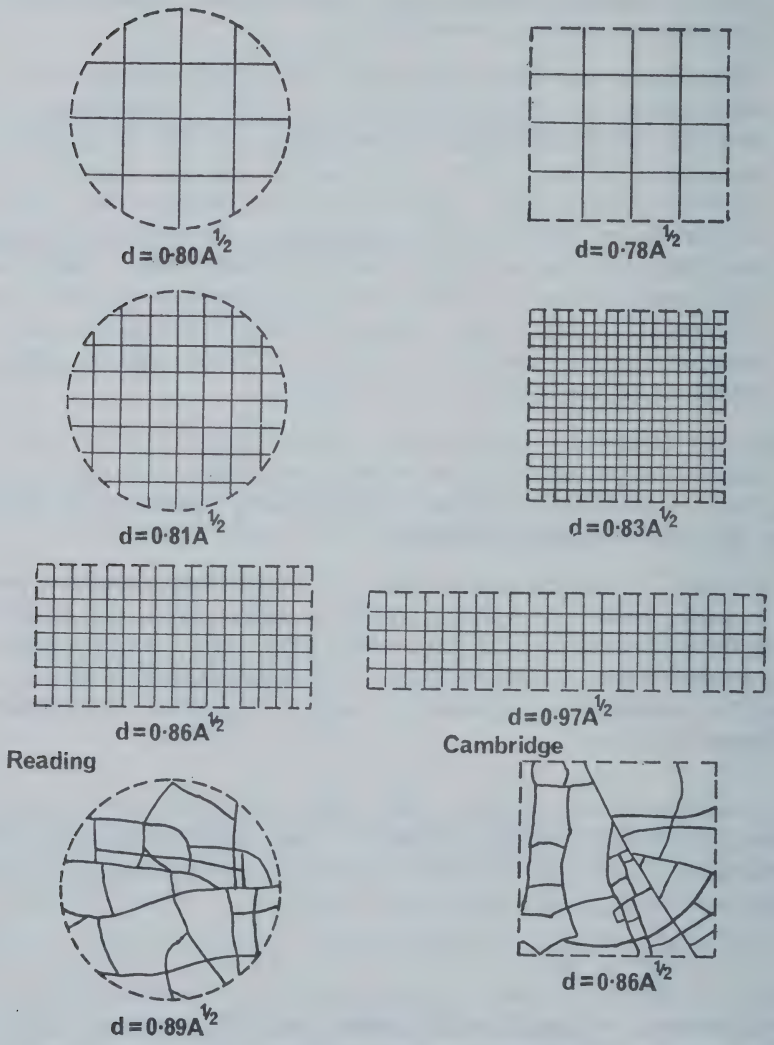


Fig. 5.2

of $0.86\ \sqrt{A} - 0.89\ \sqrt{A}$. Thus, it may be assumed that the formula that relates Kilometrage and Volume would be in the form of -

$$K \cong 0.87\ \sqrt{A}\ .\ N\ ; \qquad (5.8)$$

This formula gave excellent results for the five ring screen-lines of Tel-Aviv, but far from satisfactory for the four ring screen-lines of London.

It may be concluded, therefore, that while the coefficient of 0.87 may be applicable in certain cases, its value may change for other cases. It would be interesting, therefore, to widen the scope of the original research to large areas, or rings, and test the sensitivity of this coefficient to various parameters in the study area.

A different approach has been developed in Amsterdam, as detailed in the following paragraph.

(3) The Amsterdam Method.

In paragraph 2 of chapter 4 it has already been mentioned that a novel method of using scalar presentation of 'Dentisy Performance' had been developed in Amsterdam by ir. 't Hart et al. The 'Density Performance', however, is simply the density of person or vehicle Kilometrage per hour in each zone of the area.

By further developing the procedure (Ref. 4.10), the computed Performance Kilometrage could then be translated into traffic volumes crossing screen-lines, assuming equal traffic in every direction, by the relationship -

$$\text{Density of Kilometrage} = \frac{\pi}{2} \times \text{Traffic Volume}\ ; \qquad (5.9)$$

This method was applied with actual examples in Amsterdam, with encouraging results.

Thus, it may be concluded that such a method is available, with seemingly satisfactory results.

(4) The α - Relationship Method.

(Note: This method was developed by the author at the University College London, under a grant from the Science Research Council, U.K., on the subject of "A rapid estimation of urban transport needs". This research project was initiated with the purpose of further developing several ideas that had been forwarded in this Dissertation, and

part of the results could be added to this final edition of the Dissertation).

While analyzing traffic data in towns of various sized and characteristics in the U.K. and the U.S.A., it could be shown that there is a strong relationship between the traffic Intensity 'I', the Road Density 'R' and the Speed 'v', in the form of -

$$I = \alpha \frac{R}{v} ; \qquad (5.10)$$

where: I - is the vehicle-kilometrage of travel per unit ground area;
R - is the length of roads per unit ground area;
v - is the weighted space-mean speed.

Tab. 5.2 and Fig. 5.3 detail the relevant parameters and results for two examples, those of London and Pittsburgh - although many more examples have been analyzed in the original research.

For better graphical presentation of the results, however, the traffic intensity is related to the ratio of v/R, since on a log-log scale it results in a straight line along several fields of magnitude.

It should be pointed out that the basic data for London and Pittsburgh suffered from several restrictions. For example, in London the data was grouped together on a 'Sector' basis, while in Pittsburgh it was done for 'Rings' around the center; in both cases the vehicle-kilometers of travel were daily totals for all categories of roads, while the road lengths and speeds were for the Arterial network only; no information was given as to the average number of free-lanes of the roads, nor even the average total number of lanes; the speeds were average for off-peak periods of the day; and so on.

Nevertheless, a clear relationship between the parameters came to light, emphasizing the basic interaction between them.

Fig. 5.3-1 shows the relationship in absolute values, while Fig. 5.3-2 shows it in relative values, namely above or below the average value for the whole area.

As can be seen, while the absolute value of α may change from town to town, in relative terms the relationship holds true and is identical in both cases.

It should also be noted that the dispersion of the values around the average line is affected more by the individual characteristics of the sectors and rings than by the statistical

Table 5.2

The α -Relationship

(Daily)

LONDON - 1961

Sector	Area	Veh.Km. (ooo)	Road Length	Speed	Traffic Intensity	Road Density	α	Relative Values				
								α	I	R	v	v/R
0	392	7,350	505	41.3	18,750	1.29	601,080	1.38	1.16	1.01	1.19	1.18
1	279	4,260	307	37.3	15,270	1.10	517,575	1.19	0.95	0.86	1.08	1.26
2	209	1,425	204	50.5	6,820	0.98	352,743	0.81	0.42	0.77	1.46	1.90
3	364	5,030	378	40.3	13,820	1.04	536,272	1.23	0.86	0.81	1.16	1.43
4	105	4,400	272	25.9	41,900	2.59	418,958	0.96	2.60	2.02	0.75	0.37
5	23.4	2,680	119	19.5	114,530	5.09	439,160	1.01	7.11	3.98	0.56	0.14
6	3.6	432	21	23.0	120,000	5.83	473,133	1.09	7.45	4.55	0.66	0.15
7	169	5,125	330	30.9	30,330	1.95	479,877	1.10	1.88	1.52	0.89	0.59
8	343	2,720	386	45.0	7,930	1.13	317,115	0.73	0.49	0.88	1.30	1.48
9	545	5,750	587	41.5	10,550	1.08	406,534	0.93	0.66	0.84	1.20	1.43
	2,433.0	39,172	3,109	34.6	16,100	1.28	435,960	1.00	1.00	1.00	1.00	-
PITTSBURGH _ 1958												
0	2.6	600	79	12.9	230,770	5.98	194,428	1.13	10.74	3.71	0.39	0.11
1	10.6	513		20.9	48,400							
2	34.9	612	90	27.3	17,540	2.58	185,640	1.08	2.23	1.60	0.77	0.48
3	63.0	1,235	156	29.0	19,600	2.48	229,593	1.33	2.50	1.54	0.82	0.53
4	91.7	1,310	182	30.6	14,290	1.98	220,259	1.28	1.82	1.23	0.86	0.70
5	241.5	1,680	374	38.6	6,960	1.55	173,391	1.01	0.89	0.96	1.09	1.14
6	550.0	1,770	554	43.4	3,220	1.01	138,663	0.80	0.41	0.63	1.23	1.95
7	90.5	792	313	46.6	8,750	3.46	117,898	0.68	1.11	2.15	1.32	0.61
	1,084.8	8,512	1,748	35.4	7,850	1.61	172,398	1.00	1.00	1.00	1.00	-

(13.2 | 1,113 | 13.8 | 84,320)

References: London:- 'London Traffic Study', Vol. 1, Tables 2.1, 2.19, 3.1;
Pittsburgh:- 'Pittsburgh Area Transportation Study', Vol. 1 - Tab. 13,
Vol. 2 - Tab. 29, 40.

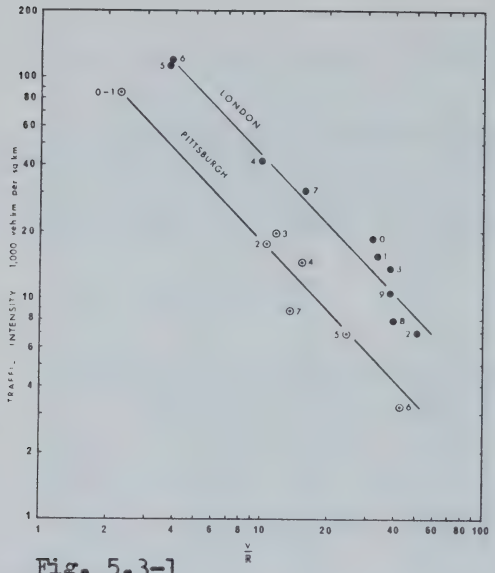


Fig. 5.3-1

The α-Relationship in absolute values

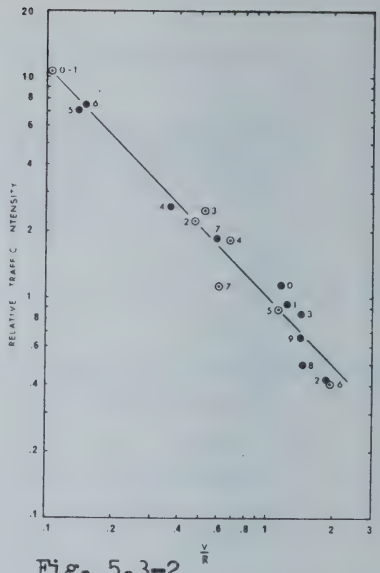


Fig. 5.3-2

The α-Relationship in relative values

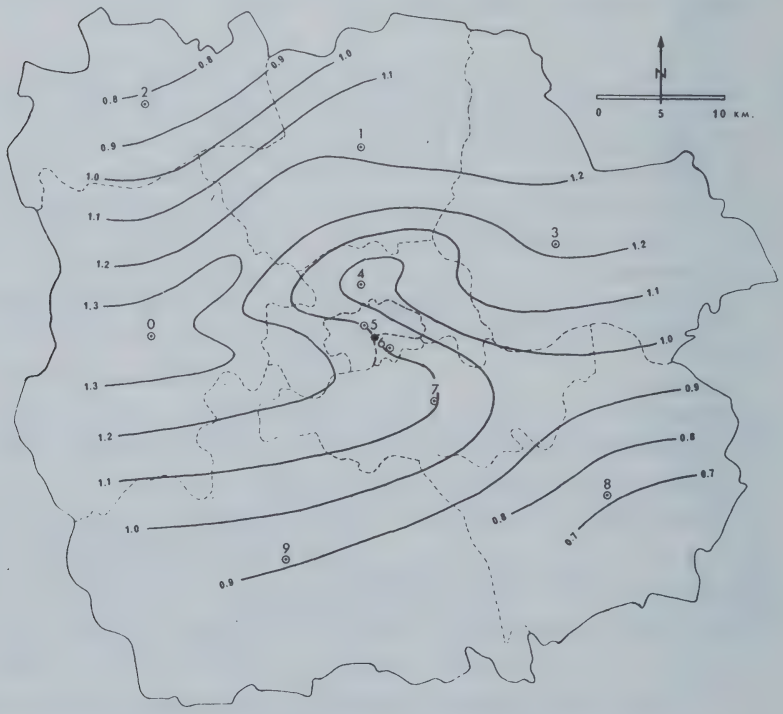


Fig. 5.3-3 The α-Map for London

Fig. 5.3

variability of the data (since the sectors and rings are very large in area and include many smaller zones).

Formula 5.10 may also be written in the form of -

$$\frac{I.v}{R} = \alpha \quad ; \tag{5.11}$$

Dividing both 'I' and 'R' by the ground areas results in the traffic flow per unit length of the road network. Thus, it may be concluded that -

$$q.v = \alpha \quad ; \tag{5.12}$$

for the range of values found for the average traffic conditions on the road networks of the sectors and rings.

Since the flow of traffic equals the concentration of traffic multiplied by its speed (see also Eq. 1.15), namely -

$$q = k.v \quad ; \tag{5.13}$$

it follows that formula 5.12 may be written in the form of -

$$q.v = k.v^2 = \alpha \quad ; \tag{5.14}$$

By considering the concentration of traffic as representative of the mass of traffic, it can be concluded that α may represent the 'kinetic energy' of the traffic, by being similar in form to $\frac{1}{2}m.v^2$, where 'm' is the mass.

It is of interest to note that the idea of using the kinetic energy of traffic flow as a measure for the efficiency of traffic flow has already been proposed in 1965 by Drew and Keese. ('Freeway Level of Service as influenced by Volume and Capacity characteristics', by D.R. Drew and C.J. Keese, HRB Record No. 99).

However, while their approach was based on theoretical considerations of analogy models, in this case it is a direct result from an empirical analysis of observation.

Moreover, while their formulation was a micro-relationship for a certain location, where the value of kinetic energy changes in accordance with the ever-changing volumes and speeds, in this case it is a macro-relationship, specifying a characteristic and constant α value for each separate zone.

At this stage two conclusions may be derived from the above short presentation:-

(a) The Traffic Performance in an area may be defined in a quantified form by its α value, since it integrates both the

amount of traffic flow and speed to represent its Level of Service;

(b) By interpolating and constructing a three-dimensional map of the α values for the zones of an urban area, it would be possible to represent the traffic performance in the whole area.

Such an example has been computed for London and is presented in Fig. 5.3-3, where the spatial distribution of equi-value lines of the relative α values are shown.

Although this map is based on only 10 α values for the huge area of London, it already portrays the known principal characteristics of the traffic performance of the Arterial network in London. The same was found for other towns as well.

Coming back to the basic subject of this paragraph, namely that of defining the spatial distribution of the Kilometrage in the area by a simplified procedure, it can be concluded that Formula 5.10 may be used for that purpose in the following way. (It should be emphasized, however, that the following procedure is aimed at deriving a rapid, first-approximation, distribution of the Kilometrage in the area, by assuming an average uniform α value for the whole area):-

(1) The road network in the urban area should be divided into zones;
(2) A sample of road sections should be chosen in several zones in such a way as to represent the average conditions in them;
(3) At each sample-section the flows and speeds of the traffic should be observed, for peak-hour or average for a whole day;
(4) The samples should then be expanded by the total road network in each zone, and the three basic parameters of I, and v/R should be calculated;
(5) The α relationship should then be derived, as presented in Fig. 5.3-1;
(6) By measuring the road density for each zone in the area directly from a map, and by observing the speeds on all or parts of the road network in each zone, the ratio of v/R for each one of the zones should then be calculated;
(7) By refering to the α relationship, the traffic density in each zone may then be derived, and by multiplying it by the zone's area the Kilometrage in that zone will then be established.

In other words, by defining the average line of the α relationship for an urban area, the Kilometrage and its distribution may then be derived easily by observing only the distribution of the speeds on the network.

If, on the other hand, an accurate estimation of the Kilometrage and the traffic performance is desired, then the representative sample should be conducted in all zones, and at a high level of statistical reliability.

In summing up this paragraph, it may thus be said that several alternatives are available to the planner for distributing the total travel demand in an urban area.

It would be advisable, however, to apply them parallely and derive their average result, to ensure a higher level of certainty.

3. Speeds on the road networks.

While analyzing the study towns road networks, several difficulties become immediately apparent, resulting from the different definitions used for the road categories and the traffic on them. For example, and as already mentioned in the previous chapters, in some towns the Expressways are included in the Freeways category, while in other towns they are included in the Arterial category; In some cases the Local network includes the basic local streets for assignment, while in other cases it includes segments only of collector streets connecting sections of the Arterial network; In most cases only partial information on the networks is presented, if by ommitting the network's length, the average number of lanes, or the assigned Kilometrage.

Similar difficulties may be found with the presentation of speeds on the networks; - In most cases base-year information is missing alltogether, while target-year speeds are based on a desired estimation and, thus, cannot be used for an accurate and conclusive quantitative analysis.

However, and in spite of all these difficulties, when the partial information from all the study towns are arranged in orderly groups and analyzed in the light of several fundamental criteria, a clear pattern begins to emerge, which enables us to arrive at some definite conclusions.

(1) Table 5.3 details the available basic information on the road networks in the study towns, for base and target years, divided into the three categories of roads, namely - Freeways, Arterials and Locals. The table includes other combinations of categories as well, - if published in that form in the study reports.

The table also includes the daily Kilometrage 'K', as well as the peak-hour Kilometrage 'K_p' It should be mentioned that while traffic values at peak-hour average about 8.5% for most towns, the peak-hour Kilometrage is higher, since most trips at that hour are work-trips, with longer trip-lengths than for other purposes.

Therefore, a common denominator of 10% has been chosen to represent the peak-hour Kilometrage.

Since the average volume per 1-km. lane 'q' per hour is found by dividing the peak-hour Kilometrage by the lane length, the next problem is to define the number of lanes for each category of roads.

In the case of Freeways, 10 study reports have detailed the average number of lanes (or the total length), and thus they are included in the table.

For Arterials and Locals, however, no such information was available. It had to be assumed, therefore, that Arterials contain on the average 2.5 free-lanes, and Locals 1.5 free-lanes. It is recognized that this is a questionable assumption, but it seems preferable to have a common denominator than consider an arbitrary value for each case separately.

The last column is that of the speed. Since in most cases the speeds presented in the study reports have been those of off-peak periods, while the Kilometrage is considered to be at peak-hour, the off-peak speeds had to be adjusted to represent peak speeds. In order to define a common denominator, for all cases, a constant reduction has been considered for each category, namely (-) 5% for Freeways, (-) 15% for Arterials, and (-) 25% for Locals.

By considering again all the above assumptions it might be expected that the results will scatter widely, since defining constant common denominators for the varied conditions in the study towns will surely spread the results all over the diagrams.

However, and in spite of all the above considerations, it is of interest to note that some clear relationships begin to emerge. It seems that the inherent characteristics of each category of roads is stronger than the differences between the categories, thus emphasizing each category separately, as follows.

(2) Fig. 5.4. presents the Volume-Speed relationship for Freeways. As can be clearly seen, the data groups itself into two distinct classes, the first for USA towns - Baltimore, Chicago, Knoxville and Columbia, with a high-standard Freeway Type 2; and the second for other towns in the world- Athens, Tel-Aviv and Kingston, with a lower standard Type 1. London is situated in between the two Freeway Types, while Bombay is far to the left, between Freeway Type 1 and Parkway.

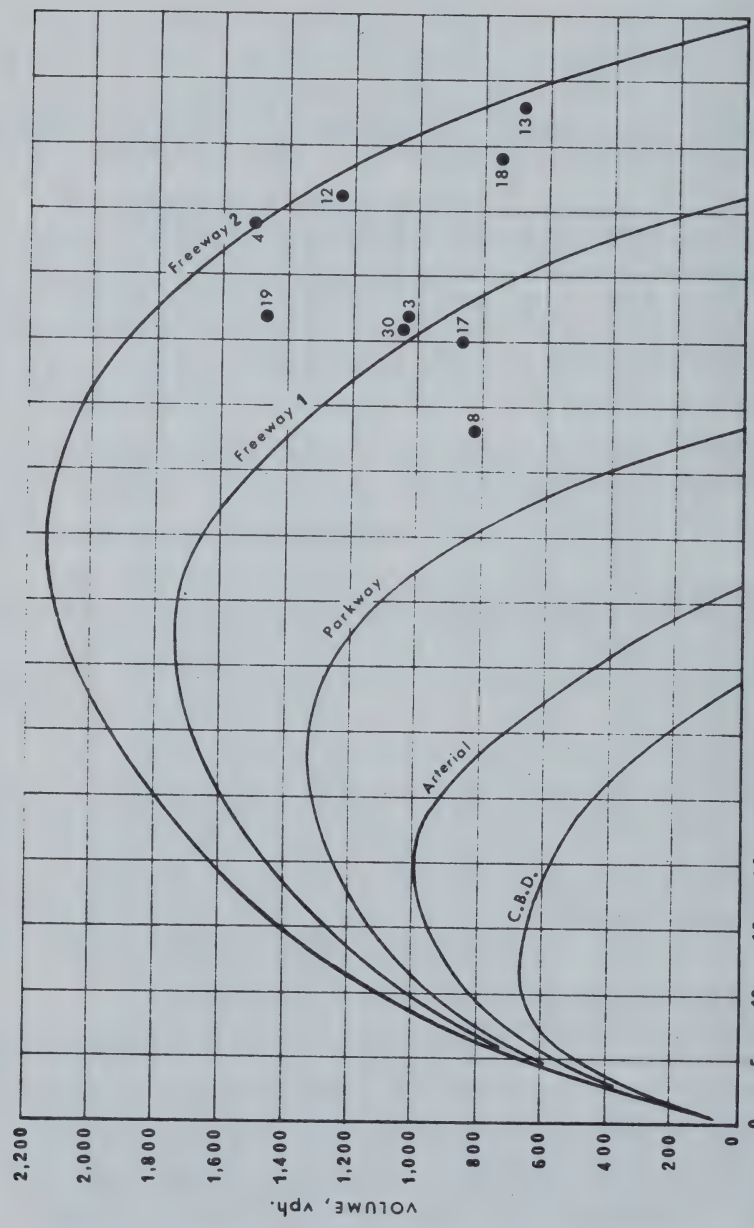
Fig. 5.5 represents the Volume-Speed relationship for Arterials. Although in this case a dispersion is noticeable, it is still clustered around the characteristic Arterial curve, signifying a consistent relationship, especially for base-year conditions. The points which are way beyond the norm are those projected to a target-year for USA towns, for which a daily average speed of over 55 kph for the Arterial network have been assumed in the original reports. However, the comparison of this assumption with the available information for all other towns immediately points out that such speeds may be considered as too high.

It should be emphasized again that Fig. 5.5 presents actual speed data for base-years as well as assumed speeds for target-years. In the

Table 5.3

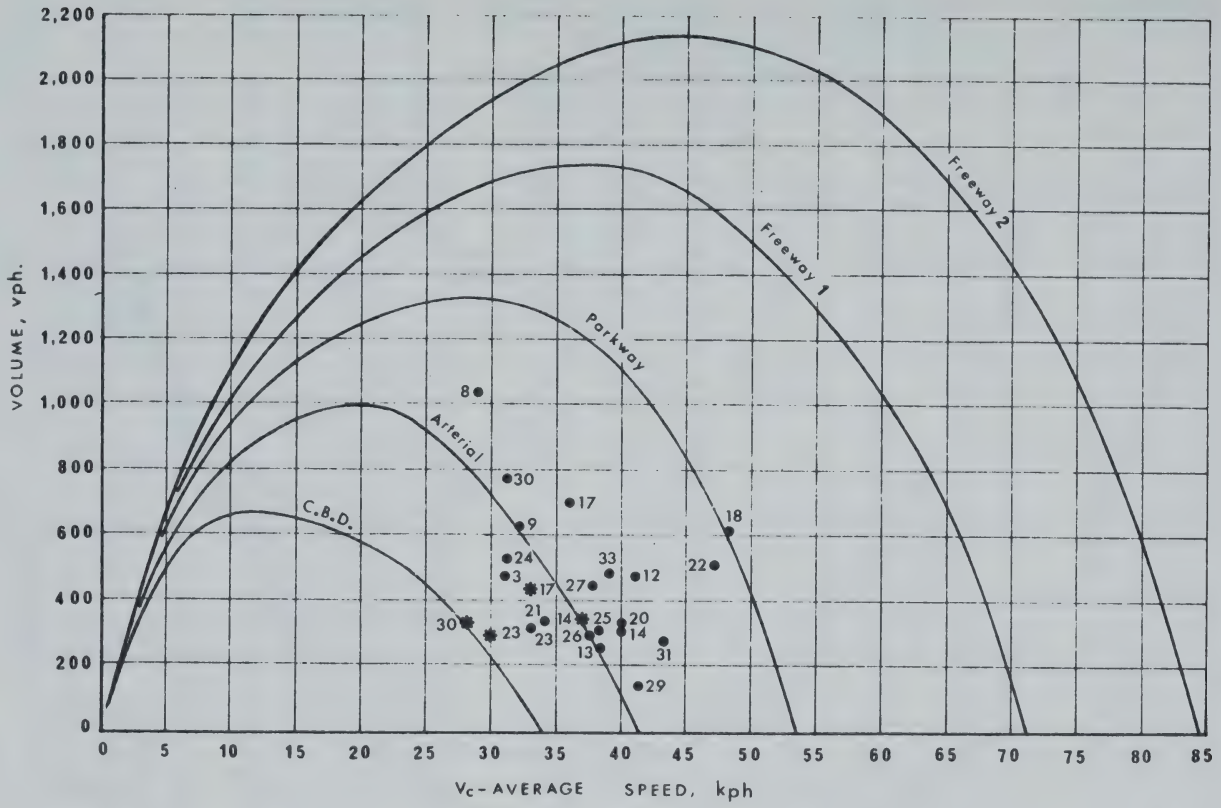
The Road Networks at Peak-hour

No.	Town	Year	K(ooo)	K_p (ooo)	L	Lanes	Total L	q	v	v_c	Remarks
Freeways											
3	Athens	80	5,800	580.0	96	5.8	558	1,040	65	62	
4	Baltimore	80	21,900	2,190.0	250	5.8	1,450	1,510	73	69	
8	Bombay	81	3,310	331.0	67	5.9	395	838	56	53	
12	Chicago	80	55,400	5,540.0	840	5.3	4,450	1,242	75	71	
13	Columbia	85	4,050	405.0	142	4.2	595	680	82	78	F & E
17	Kingston	81	728	72.8	17	4.9	84	867	63	60	
18	Knoxville	82	3,120	312.0	104	4.0	416	750	78	74	
19	London	81	55,200	5,520.0	542	6.9	3,745	1,475	65	62	
30	Tel-Aviv	85	3,422	342.2	68	4.8	326	1,050	64	61	
Arterials											
3	Athens	80	5,450	545.0	458	2.5	1,140	478	36	31	
8	Bombay	81	6,440	644.0	246	"	615	1,045	34	29	
12	Chicago	80	53,300	5,330.0	4,500	"	11,250	473	48	41	
14	Copenhagen	67	12,951	1,295.1	1,480	"	3,700	350	44	37	
	"	85	13,800	1,380.0	1,765	"	4,410	313	47	40	
17	Kingston	67	1,045	104.5	96	"	240	436	39	33	
	"	81	1,945	194.5	111	"	278	700	42	36	
18	Knoxville	82	4,750	475.0	244	"	610	780	56	48	
20	Melbourne	85	27,400	2,740.0	3,060	"	7,650	358	47	40	
22	Orlando	85	10,900	1,090.0	864	"	2,160	505	55	47	
23	Pittsburgh	58	12,250	1,225.0	1,750	"	4,370	281	35	30	
	"	80	13,250	1,325.0	(1,750)	"	(4,370)	303	39	33	
24	Ponce	85	1,222	122.2	84	"	210	534	36	31	
26	Rapid City	85	1,393	139.3	193	"	482	289	43	37	
29	Sioux Falls	85	1,610	161.0	462	"	1,155	140	48	41	
30	Tel-Aviv	65	1,433	143.3	172	"	430	336	33	28	
	" "	85	4,767	476.7	243	"	608	784	36	31	
31	Tucson	80	6,350	635.0	935	"	2,340	272	51	43	
Locals											
8	Bombay	81	614	61.4	670	1.5	1,000	61	22	17	
14	Copenhagen	67	1,859	185.9	545	"	817	227	39	29	
	"	85	391	39.1	545	"	817	48	(30)	22	
17	Kingston	67	437	43.7	136	"	204	214	38	28	
	"	81	830	83.0	147	"	220	378	39	29	
18	Knoxville	82	830	83.0	345	"	517	160	36	27	
30	Tel-Aviv	65	441	44.1	121	"	181	224	21	16	
	" "	85	1,702	170.2	(125)	"	(188)	(905)	20	15	
Arterial plus Local											
9	Brisbane	81	7,290	729.0	330	2.2	1,170	623	40	32	
13	Columbia	85	2,570	257.0	507	"	1,043	246	48	38	
21	Monroe	85	2,030	203.0	272	"	621	327	43	34	
25	Pulaski	90	3,750	375.0	555	"	1,245	301	47	38	
27	Richmond	80	6,960	696.0	715	"	1,570	444	48	38	
33	Winston Sal'	85	2,220	222.0	211	"	464	480	49	39	



SPEED - VOLUME RELATIONSHIP
FREEWAYS

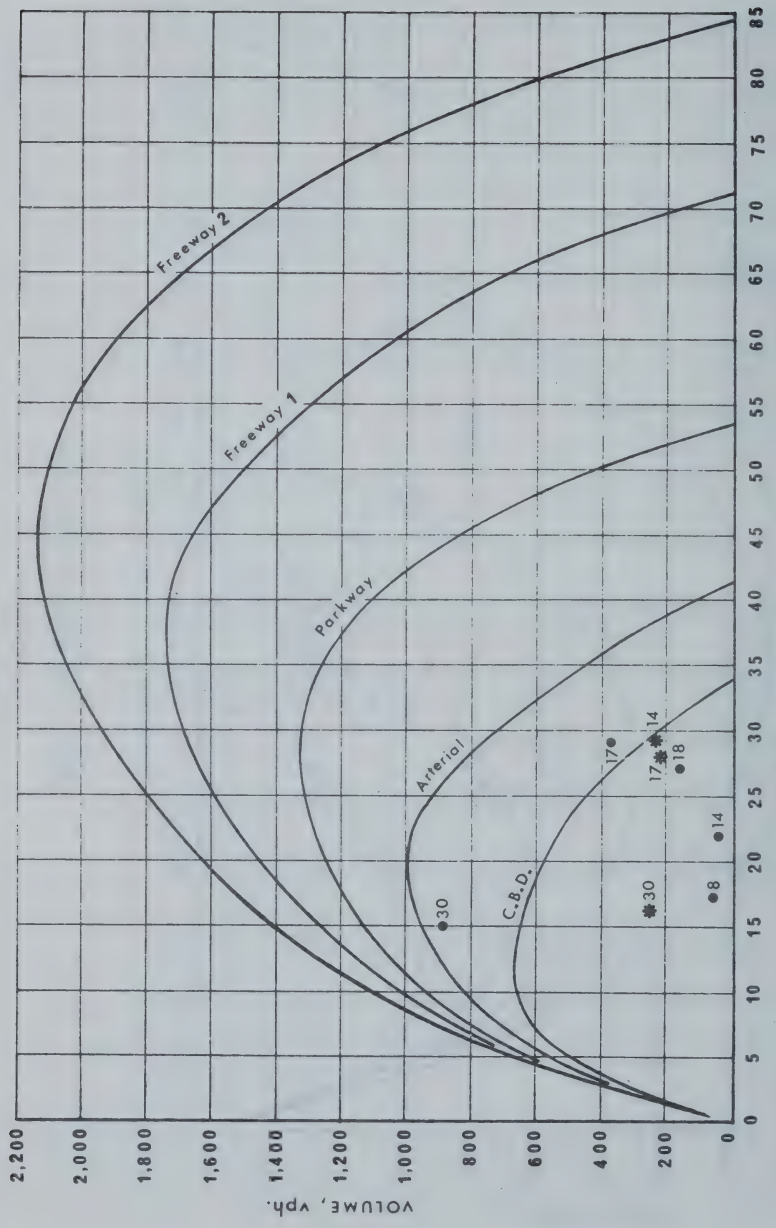
Fig. 5.4



SPEED – VOLUME RELATIONSHIP

ARTERIALS

Fig. 5.5



SPEED – VOLUME RELATIONSHIP
LOCALS

Fig. 5.6

case of other towns than the USA, however, the points on the graph intermingle, thus showing a reasonable level of planning assumptions, based on current operational experience. Even the dispersion around the curve is within an acceptable range for most towns, especially so when considering the many probable irregularities of the Arterial network definition in each separate town as, for example, by including many different types of roads in that category, or by the assumption of an average width of 2.5 free-lanes.

Fig. 5.6 represents the Volume-Speed relationship for the Local network. In this case, however, an unstable situation presents itself, where the points do not correspond with the CBD curve. Nevertheless, two considerations should be pointed out in this case, namely - the CBD curve represents an average operational condition for a typical CBD network which includes, by its definition, not only Local but other categories of roads as well; and that the Local network, as such, has never been considered as a critical part in the total network's analysis or planning. It is not surprizing therefore, that the Local networks carry very low volumes, below the CBD curve. (Only the point Tel-Aviv 1985 is way above the average, thus showing again what has already been mentioned before (Tab. 2.3), namely that the length for the 1985 assignments practically remained the same as that for the 1965 assignment). It may be assumed, therefore, that all Local networks are situated on a separate flat curve below the composit CBD curve.

(3) After each category of roads has thus been separately checked, a total average has then been computed, as presented in Tab. 5.4 and Fig. 5.7.

In this case, however, all the limitations mentioned before have accumulated together, severely limiting the number of examples, (especially for the target years since only 10 towns reported the average width of the Freeway network). For instance, only two towns, Kingston and Tel-Aviv, present full data for all the three categories of roads and for base as well as for target years; two other towns only, Copenhagen and London, present such full data for the base years; while Bombay presents it for the target year.

The figure includes also four more towns, Athens, Chicago, Columbia and Knoxville, which present data for Freeway plus Arterial networks only. and for target years, with no information on the Local network.

Although the limitations of the available published data has severely restricted the number of cases, Fig. 5.7 shows some trends which may be considered reasonable and within expectations.

For example, although the average volumes increase appreciably from base to target years for Kingston and Tel-Aviv, the expected speeds increase as well as a result of the addition of Freeways; all towns are

situated within an average volume-range of 300 to 500 for base-year, and 400-800 for target-year, though the average speeds may differ to a considerable extent depending on the level of service planned for them.

Table 5.4

The Total Networks at Peak-hour

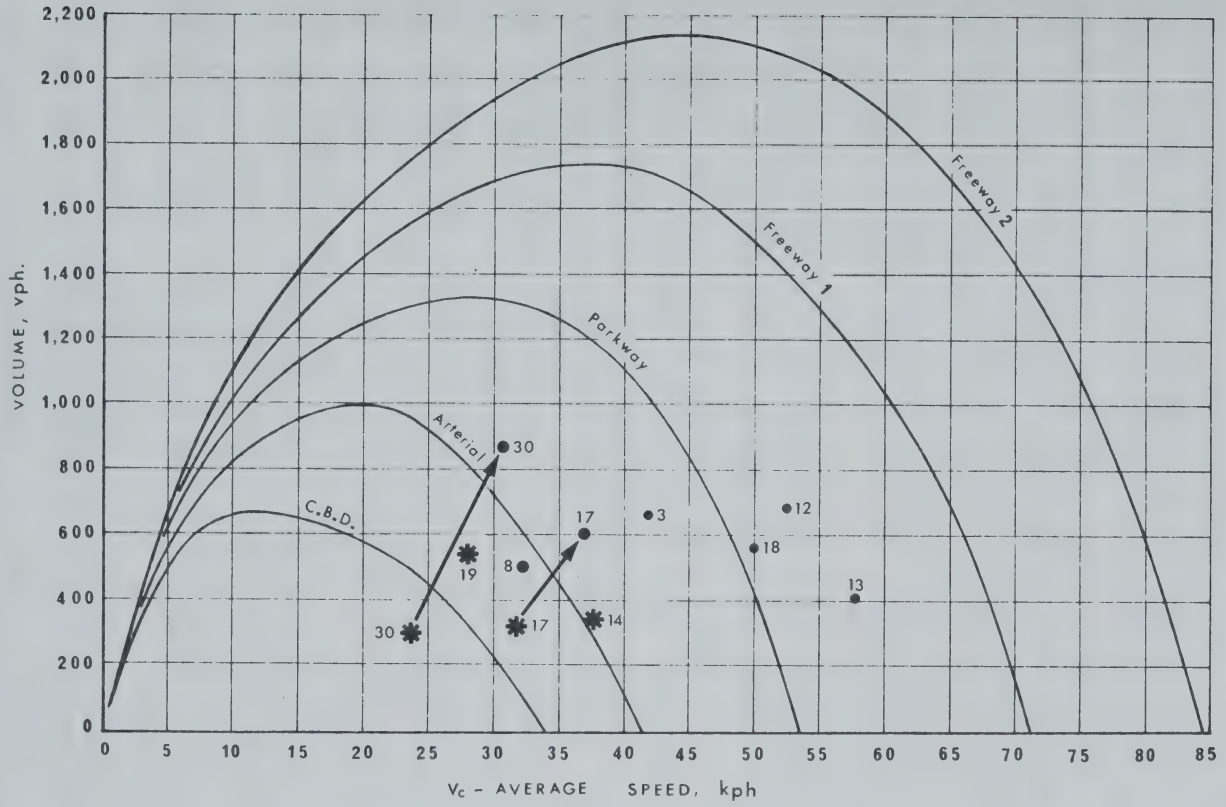
No.	Town	Year	K (ooo)	K_p (ooo)	Total L	q	v_c
8	Bombay	81	10,364	1,036.4	2,010	516	32.3
13	Columbia	85	6,620	662.0	1,638	405	57.8
14	Copenhagen	67	16,038	1,603.8	4,693	342	37.5
17	Kingston	67	1,482	148.2	444	335	31.4
	"	81	3,503	350.3	582	602	36.9
18	Knoxville	82	8,700	870.0	1,543	564	50.0
19	London	61	39,200	3,920.0	7,210	544	28.0
30	Tel-Aviv	65	1,874	187.4	611	306	23.8
	" "	85	9,891	989.1	1,122	880	30.6
Total excluding Locals							
3	Athens	80	11,250	1,125.0	1,698	662	41.7
12	Chicago	80	108,700	10,870.0	15,700	692	52.3

(4) Looking again at Fig. 5.7 it becomes apparent that a town may be defined - trafficwise - by two simple criteria:- its average volume versus its average speed. The same applies to the α value (paragraph (2) in this chapter), which expresses the combined effect of the average volume and speed.

In other words, a transportation planner may define a desired average traffic condition or performance for a target-year, based on the existing condition, and then analyze what that desired condition entails on the planning requirements.

Moreover, not only different alternatives of road networks may then be evaluated, but even an economic analysis may be carried-out, as will be mentioned later-on.

At this stage, however, the time has come to show how the 'IN' model may be integrated within the analysis framework, and what are its practical applications.



THE TOTAL ROAD CATEGORY

Fig. 5.7

4. The 'IN' Model.

As already shown in Eq. 1.5. the INstant number of vehicles on a road network may be derived from the simple relationship $IN = K_p/v$, where 'K_p' is the hourly Kilometrage and 'v' is the hourly average speed. This relationship will be analyzed now by applying the available data from the study towns.

Table 5.5 details the data for the three categories of roads, including the peak-hour Kilometrage and the average speed at that hour.

Dividing the Kilometrage by speed results in the INstant number of vehicles, which is then compared in per cent to the total number of vehicles.

Since the total number of vehicles (passenger cars plus commercial vehicles) is a critical factor, only towns for which these two classes are clearly defined are included.

Fig 5.8 presents the relationship between the IN percentage and the level of motorization for each category or roads. All categories show concave-shaped curves with varying degrees of curvature.

The projected values of the Freeways IN are clustered around the average curve in a clear way, with a range of 2-4% only.

For the Arterials IN values, which include base as well as target year data, two characteristic flat curves may be defined, one for each group of years. While for base-year data all towns but one conform to the average, for target-year data a higher dispersion is expected - and noted. Nevertheless, the general trend is clear.

The same characteristic trend is also found for the Locals IN, where all base-year data conform to a clear relationship, while that for target-year data is somewhat more dispersed.

Table 5.5 and Fig. 5.9 present the total weighted average for all categories put together. It should be noted, therefore, that only towns for which the data for all three categories is available are shown.

The trend of the IN percentage is of particular interest, since it shows a rapid decline with the increase of motorization up to about 15% and then a moderate decrease.

And again the general trend is established, where base-year data are highly related, while target-year data are more pronouncely scattered.

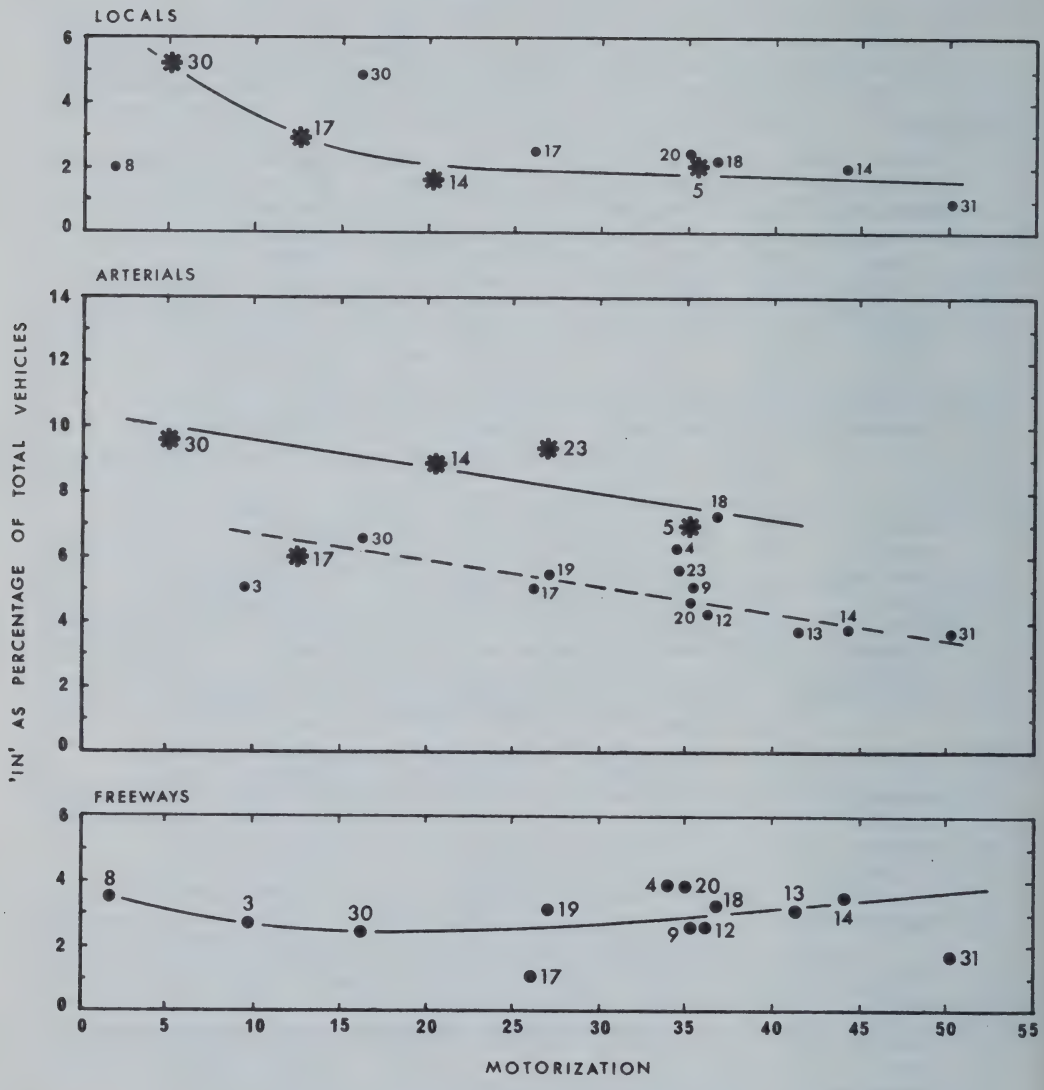
It may thus be concluded that an assumption that is projected to a future date in a transportation study does not always adhere strictly to factual and established relationships, but may rather reflect some degree of wishing and hopes.

Table. 5.5

The 'IN' Number of Vehicles on the Road Networks

At Peak-Hour

No.	Town	Year	K_p (ooo)	v	v_c	IN	Mot. %	Total Veh.	IN-%	Remarks
Freeways										
3	Athens	80	580	65	62	9,360	9.6	350,000	2.68	
4	Baltimore	80	2,190	73	69	31,800	33.9	807,270	3.94	
8	Bombay	81	331	56	53	6,250	1.9	180,753	3.46	
9	Brisbane	81	757	74	70	10,810	35.4	422,800	2.56	
12	Chicago	80	5,540	75	71	78,000	36.2	3,039,000	2.57	
13	Columbia	85	(405)	82	78	5,190	41.3	169,780	3.06	F & E
14	Copenhagen	2000	(2,560)	85	81	31,600	44.2	915,350	3.45	F & E
17	Kingston	81	73	63	60	1,210	26.1	108,989	1.11	
18	Knoxville	82	312	78	74	4,210	36.6	135,490	3.11	
19	London	81	5,520	65	62	89,100	27.0	2,794,000	3.19	
20	Melbourne	85	3,700	67	64	57,800	35.0	1,485,400	3.89	
30	Tel-Aviv	85	342	64	61	5,610	16.1	233,133	2.41	
31	Tucson	80	515	81	77	6,700	52.0	403,100	1.66	
Arterials										
3	Athens	80	545	36	31	17,600	9.6	350,000	5.04	
4	Baltimore	80	1,910	45	38	50,300	33.9	807,270	6.23	A & E
5	Baton Rouge	65	257	46	39	6,600	35.2	95,217	6.94	
8	Bombay	81	644	34	29	22,200	1.9	180,753	12.30	
9	Brisbane	81	729	40	34	21,450	35.4	422,800	5.08	A & L
12	Chicago	80	5,330	48	41	130,000	36.2	3,039,000	4.28	
13	Columbia	85	257	48	41	6,270	41.3	169,780	3.70	A & L
14	Copenhagen	67	1,295	44	37	35,000	20.1	390,190	8.96	
	"	85	1,380	47	40	34,600	44.2	915,350	3.78	
17	Kingston	67	105	39	33	3,180	12.5	52,652	6.04	
	"	81	195	42	36	5,420	26.1	108,989	4.98	
18	Knoxville	82	475	56	48	9,900	36.6	135,490	7.32	
19	London	81	4,645	36	31	150,000	27.0	2,794,000	5.37	A & L
20	Melbourne	85	2,740	47	40	68,500	35.0	1,485,400	4.61	
23	Pittsburgh	58	1,225	35	30	40,800	26.9	437,224	9.35	
	"		1,325	39	33	40,200	34.4	715,963	5.62	
30	Tel-Aviv	65	143	33	28	5,100	4.9	52,713	9.67	
	" "	85	477	36	31	15,400	16.1	233,133	6.60	
31	Tucson	80	635	51	43	14,750	52.0	403,100	3.66	
Locals										
5	Baton Rouge	65	35.5	23	17	2,090	35.2	95,217	2.20	
8	Bombay	81	61.4	22	17	3,610	1.9	180,753	2.00	
14	Copenhagen	67	185.9	39	29	6,400	20.1	390,190	1.64	
	"	85	39.1	(30)	22	1,780	44.2	915,350	0.20	
17	Kingston	67	43.7	38	28	1,560	12.5	52,652	2.96	
	"	81	83.0	39	29	2,860	26.1	108,989	2.62	
18	Knoxville	82	83.0	36	27	3,070	36.6	135,490	2.26	
20	Melbourne	85	805.0	30	22	36,600	35.0	1,485,400	2.46	
30	Tel-Aviv	65	44.1	21	16	2,760	4.9	52,713	5.24	
	" "	85	170.2	20	15	11,340	16.1	233,133	4.87	
31	Tucson	80	100.0	38	28	3,570	52.0	403,100	0.89	



'IN' ON THE ROAD NETWORKS

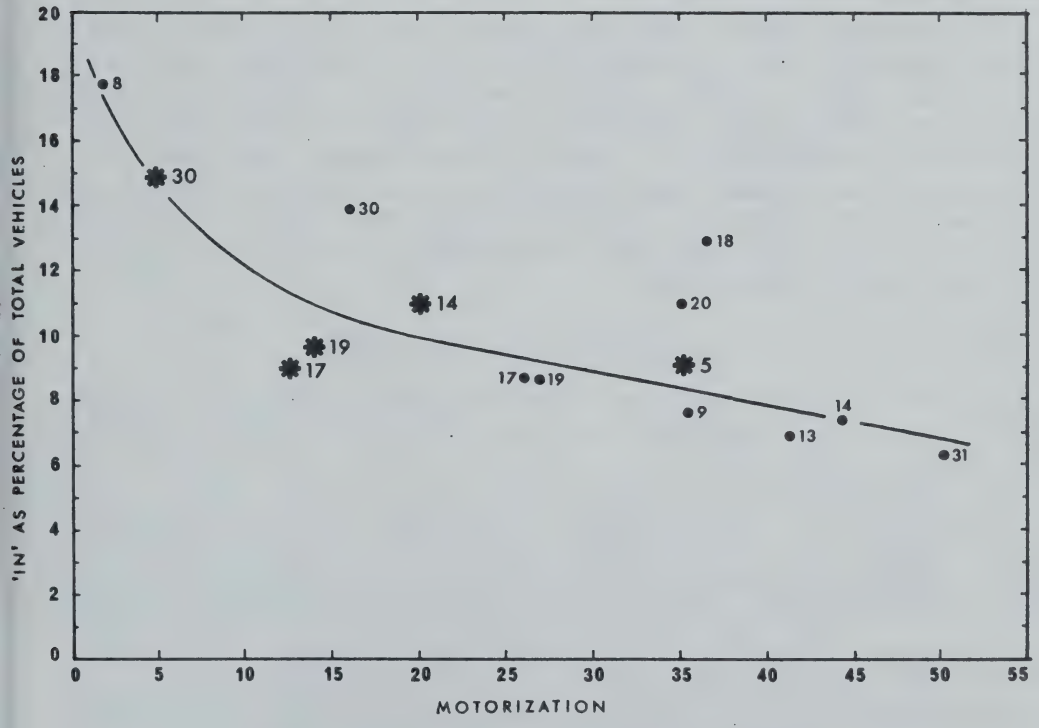
Fig. 5.8

Table 5.5 (Cont.)

The Total 'IN' Number

At Peak-Hour

No.	Town	Year	F	The 'IN' A	L	Total IN	Mot.	Total Veh.	IN %	Remarks
5	Baton Rouge	65	167	6,600	2,090	8,857	35.2	95,217	9.00	
8	Bombay	81	6,250	22,200	3,610	32,060	1.9	180,753	17.75	
9	Brisbane	81	10,810	21,450	-	32,260	35.4	422,800	7.63	A & L
13	Columbia	85	5,190	6,270	-	11,460	41.3	169,780	6.76	A & L
14	Copenhagen	67	1,320	35,000	6,400	42,720	20.1	390,190	10.95	
	"	85	31,600	34,600	1,780	67,980	44.2	915,350	7.42	
17	Kingston	67	-	3,180	1,560	4,740	12.5	52,652	9.98	
	"	81	1,210	5,420	2,860	9,490	26.1	108,989	8.72	
18	Knoxville	82	4,210	9,900	3,070	17,180	36.6	135,490	12.68	
19	London	61	-	-	-	140,000	14.1	1,440,207	9.72	
	"	81	89,100	150,000	-	239,000	27.0	2,794,000	8.56	A & L
20	Melbourne	85	57,800	68,500	36,600	162,900	35.0	1,485,400	10.98	
30	Tel-Aviv	65	-	5,100	2,760	7,860	4.9	52,713	14.92	
	" "	85	5,610	15,400	11,340	32,350	16.1	233,133	13.90	
31	Tucson	80	6,700	14,750	3,570	25,020	52.0	403,100	6.22	



THE TOTAL 'IN' ON THE ROAD NETWORKS

Fig. 5.9

At this stage it is of interest to note that the total percentage of the IN varies according to motorization from a very high percentage of about 18 at low levels of motorization, and down to about 6 per cent only at high levels of motorization. Most existing conditions at base-year are around the 10 per cent.

This last figure was tested for its ability to synthesize the total 'IN' number of vehicles on a road network, as detailed in Tab. 5.6 and presented in Fig. 5.10. As can be seen, the synthesized results are highly correlated with the given ones, where in only one case for base-year and one case for target-year, out of 15 cases, the synthesized results are beyond the acceptable limits of accuracy.

It thus may be conluded that the IN procedure may be considered as a useful tool for a rapid, first-approximation synthesis of the number of vehicles moving on an urban network at peak-hour; which is, in essence, one of the most important factors for defining the present - or projected - traffic demands in an urban area.

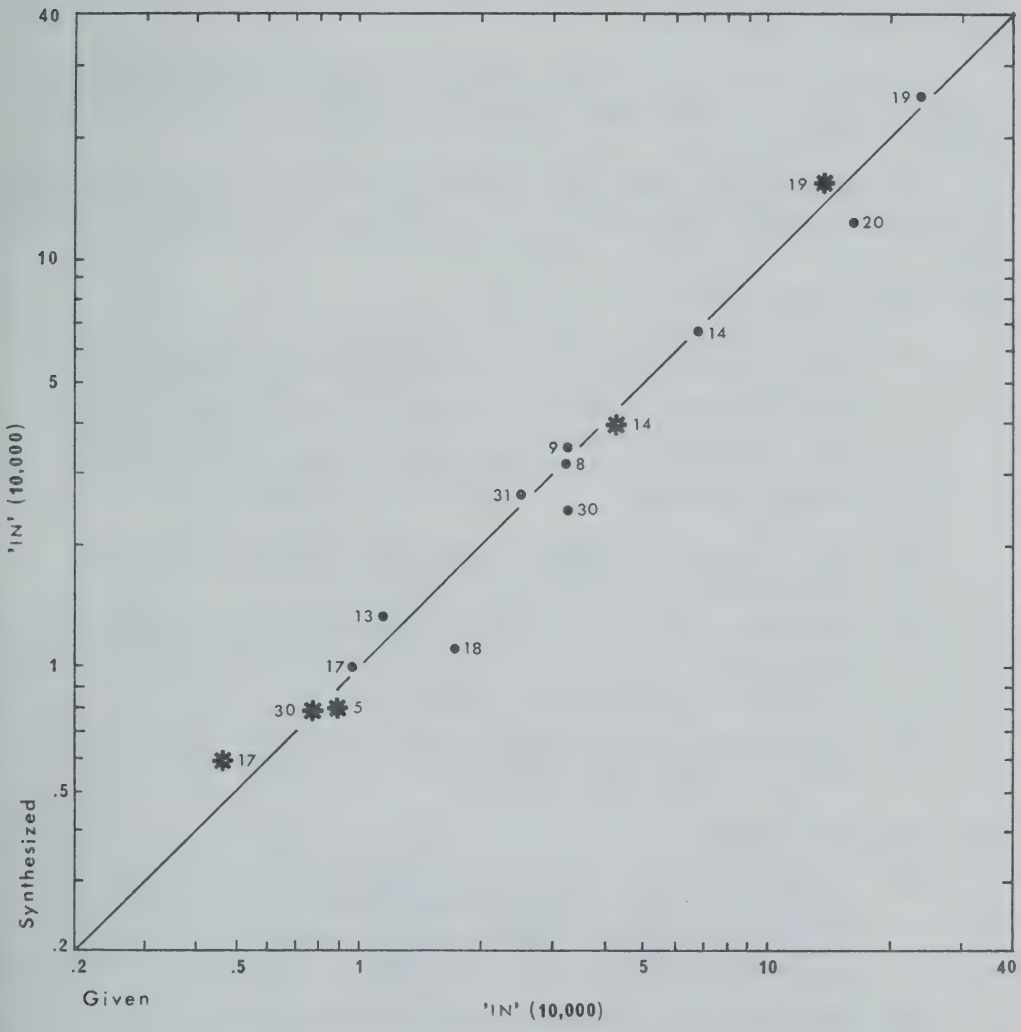
Moreover, the 'IN' procedure combines two crucial aspects of the traffic conditions, since on one hand the IN number represents the number of vehicles actually moving on the road network, thus reflecting a physical aspect of the lane lengths, while on the other hand the same number also represents the vehicle-hours of travel for those vehicles (which may be transformed into speeds), thus reflecting a crucial aspect of the times and economics of the traffic flow. The IN procedure may, therefore, be applied for a better and more perspective understanding of the complex dynamics of travel on the road networks.

Table 5.6

Synthesizing the Total 'IN'

No.	Town	Year	Total Veh.	Mot.	IN %	Synth. IN	Given IN	Diff. %
5	Baton Rouge	65	95,217	35.2	8.4	8,000	8,857	- 9.7
8	Bombay	81	180,753	1.9	17.3	31,200	32,060	- 2.7
9	Brisbane	81	422,800	35.4	8.2	34,650	32,260	+ 7.4
13	Columbia	85	169,780	41.3	7.7	13,080	11,460	+ 14.1
14	Copenhagen	67	390,190	20.1	10.0	39,020	42,720	- 8.7
	"	85	915,350	44.2	7.4	67,750	67,980	- 0.3
17	Kingston	67	52,652	12.5	11.3	5,950	4,740	+ 25.6
	"	81	108,989	26.1	9.2	10,000	9,490	+ 4.3
18	Knoxville	82	135,490	36.6	8.1	11,000	17,430	- 36.9
19	London	61	1,440,207	14.1	10.8	155,500	140,000	+ 11.1
	"	81	2,794,000	27.0	9.2	257,000	239,000	+ 7.5
20	Melbourne	85	1,485,400	35.0	8.4	124,800	162,900	- 23.4
30	Tel-Aviv	65	52,713	4.9	14.7	7,750	7,860	- 1.4
	" "	85	233,133	16.1	10.6	24,700	32,350	- 23.6
31	Tucson	80	403,100	52.0	6.7	27,000	25,020	+ 7.9

In the next paragraph a detailed example of the practical application of the 'IN' procedure, as well as the 'Density Method' developed in this research, will be presented.



SYNTHESIZED vs. GIVEN 'IN'

Fig. 5.10

5. Synthesizing a Road Network.

(1) It has already been shown how the total vehicle Kilometrage in an urban area may be distributed over the area, and how the roads carrying this Kilometrage may be calculated. In this paragraph Freeway and Arterial networks - which are the backbone of transportation planning - will be synthesized by two methods, and a comparison will be made between the derived results versus the given ones.

The first method, as already presented in chapter 3, is based on the Kilometrage and road-length densities, while the second method is based on the 'IN' procedure.

The first computed example will be the synthesis of Freeway networks, and Table 5.7 detailes the procedures of synthesis, according to the following steps:-

(I) The Density Method:

(a) The first step is to derive the percentage of the Kilometrage assigned to Freeways from the total daily Kilometrage. By refering back to Fig. 3.5 (p. 101), it is possible to estimate this percentage as related to the number of passenger-cars, and thus calculate the expected Kilometrage assigned to the Freeway network.

(b) The Kilometrage density is then found by dividing the total Kilometrage by the area.

(c) Refering to Fig. 3.6 (p. 103) it is then possible to define the lane density Factor of the Freeway network that will be required to answer the Kilometrage density demand.

(d) Multiplying the lane density by the area results, therefore, in the total lane-length of the Freeway network in the area.

(II) The 'IN' Method.

(a) The first step is to derive the INstant number of vehicles at peak-hour on the Freeway network. This is done by refering to Fig. 5.8 (p. 176). Multiplying the percentage by the total number of vehicles results, therefore, in the total 'IN' number.

(b) The next step is to decide on the desired average speed on the Freeway network at peak-hour, as well as on the desired Category Type. By refering then to Fig. 1.3. (p. 29) it is possible to derive the expected average vehicle-spacing.

(c) Multiplying the average vehicle-spacing by the IN number results in the total lane-length that is needed to accomodate the moving vehicles at the desired speed.

Table 5.7

Synthesizing the Freeway Network by two methods

1. The Density Method

No.	Town	Area	Pass. Cars	Total K (ooo)	% on F	K on F	K Density	Factor	Synth. Length
1	Adelaide	1,120	443,000	15,335	51	7,820	6,980	0.70	774
3	Athens	448	270,000	12,000	46	5,510	12,300	1.10	493
4	Baltimore	2,220	734,270	41,000	52	21,300	9,600	0.90	2,000
8	Bombay	850	148,753	10,364	32	3,320	3,910	0.50	395
12	Chicago	1,430	2,828,000	108,700	53	57,500	40,250	3.20	4,570
16	Helsinki	738	429,000	21,649	51	11,050	15,000	1.30	960
17	Kingston	107	97,170	3,503	19	665	6,220	0.65	70
18	Knoxville	1,360	122,740	8,700	26	2,260	1,660	0.30	408
19	London	2,450	2,465,000	101,650	53	53,800	22,000	1.70	4,160
30	Tel-Aviv	190	197,570	9,891	39	3,860	20,500	1.70	322

2. The 'IN' Method

No.	Town	Total Veh.	Mot.	IN-%	IN	v	F Category	Vehicle Spacing	Synth. Length
3	Athens	350,000	9.6	2.7	9,450	62	1	68	643
4	Baltimore	807,270	33.9	2.9	23,400	69	2	54	1,265
8	Bombay	180,753	1.9	3.6	6,500	53	1	39	254
12	Chicago	3,039,000	36.2	3.0	91,200	71	2	59	5,370
16	Helsinki	467,900	39.0	3.1	14,500	(62)	1	68	985
17	Kingston	108,989	26.1	2.6	2,830	60	1	59	167
18	Knoxville	135,490	36.6	3.0	4,070	74	2	72	294
19	London	2,794,000	27.0	2.6	72,700	62	1-2	39-67	3,850
30	Tel-Aviv	233,133	16.1	2.4	5,600	61	1	62	347

Average of both Methods

No.	Town	Method 1	Method 2	Average L	Given L	Diff. %
1	Adelaide	774	-	774	682	+ 13.5
3	Athens	493	643	568	558	+ 1.8
4	Baltimore	2,000	1,265	1,633	1,450	+ 12.6
8	Bombay	425	254	340	395	- 13.9
12	Chicago	4,570	5,370	4,970	4,450	+ 11.7
16	Helsinki	960	985	973	1,068	- 8.9
17	Kingston	70	167	118	85	+ 38.8
18	Knoxville	408	294	351	416	- 15.6
19	London	4,160	3,850	4,050	3,745	+ 8.1
30	Tel-Aviv	322	347	335	326	+ 2.8

(d) At this stage two different feed-back processes may be applied, for a more reliable estimate: (1) Dividing the peak-hour Kilometrage by the IN number results in the speed. This derived speed may then be compared with the desired one; (2) Dividing the peak-hour Kilometrage by the lane-length results in the average volume per 1-km of lane length. Thus, by refering again to Fig. 5.4. (p.168), a second estimate of the expected speed is derived.

It should be noticed, therefore, that these two tests may be applied in various combinations, by changing the order of the computation steps:- since the IN number is related to the speed, and vice versa, while the vehicle-spacing is also related to that speed, it is possible to first divide the peak-hour Kilometrage by the IN number, and by the derived speed to compute the vehicle spacing; and so forth.

The final lane-length of Freeways may then be computed as the average of the above two methods, as detailed in Tab. 5.7. As can be seen, the differences between the synthesized results and the given data are within the acceptable levels of accuracy. Only in one example, that for Kingston, is the difference above the acceptable level, but then not only is the absolute lane-length quite small, but it is also on the border of deciding whether a Freeway network is warranted at all.

Fig.5.11 presents a graphical comparison of the synthesized versus the given lane-lengths. As can be seen, the comparison shows an acceptable agreement along a wide range of lengths, from about 100 km and up to 5,000 km of Freeway lane lengths.

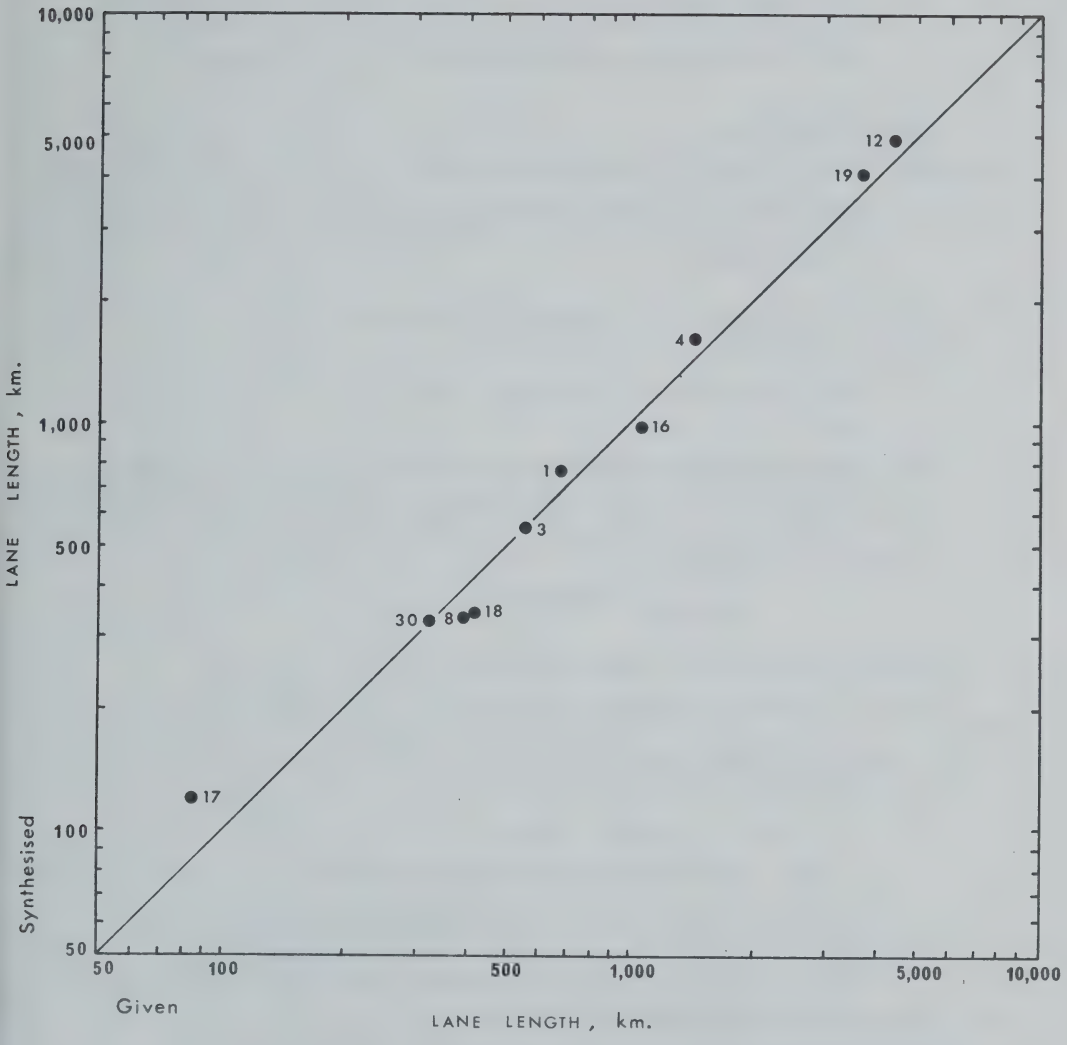
It may be concluded, therefore, that although the original given plans are not absolute, as such, but probably are strongly affected by the planners' methodology and believes, or by local policies (such as an enforced Modal-Split ratio), and although the procedures developed in this research are not flawless, nevertheless the synthesis results are consistent and within acceptable levels of accuracy.

(2) The same basic procedure may also be applied to the synthesis of the Arterial network. Following is a computed example of such a network, that of Tel-Aviv for base-year data.

(I) The Density Method.

(a) The original daily Kilometrage on the Arterial network is 1,433,000 veh.km. Thus, at peak-hour, assuming a 10%, it is 143,300 veh.km.

(b) The average Kilometrage density is, therefore - 143,300/190 = = 7,530, and by refering to Fig. 3.8 (p. 110), the expected road density is 0.85.



SYNTHESISED VS. PLANNED FREEWAY NETWORKS

Fig. 5.11

(c) Multiplying the road density by the study area will then result in the total expected Arterial road length, namely - 0.85 x 190 = 162 km.

The given length is 172 km. (Tab. 5.3, p. 167). Thus, the synthesized length is within (-) 5.8% of the given one, a difference which may be considered as quite acceptable.

(II) The "IN' Method.

(a) The expected 'IN' number of vehicles on the Arterial road network may be derived from Fig. 5.8 (p. 176), and is found to be 10% of the total number of vehicles; the IN is, therefore, 5,271 vehicles.

(b) The average speed should then be, according to v = K/IN, v = 143,300/5,271 = 27.2 kph.

The given speed, according to Tab. 5.3 (p. 167) is - 28 kph, namely a very good agreement is found.

(c) The vehicle spacing on the Arterial network for base-year conditions may be found from formula 1.17 (p. 24), namely Spacing = Speed/Flow, and using the actual traffic flow from Tab. 5.3 (p. 167) results in -

$$\text{Spacing} = \frac{1,000 \times 27.2}{336} = 81 \text{ m.}$$

(d) The total length will, therefore, be -

Lane - Length = 5,271 x 81/1,000 = 427 km.

By dividing the lane-length by 2.5 free-lanes per road, it follows that the Road-Length is -

Road - Length = 427/2.5 = 171 km.

- which is in complete agreement with the given value of 172 km.

Moreover, the same feed-back process mentioned above, may also be used in this case for a better estimation, and the final result should preferably be derived from the average of the two synthesis methods.

(3) While summarizing the above examples, it is believed that the procedures developed in this research stand up to the tests and may be used for synthesizing transportation data with sufficient accuracy for a first-approximation evaluation.

In the next paragraph it will be shown that the proposed procedures may also produce sufficient data for a first-approximation economical feasibility analysis not only for the transportation plan which may be developed

by the procedure, but also for various alternatives of plans, based on different planning-assumptions.

This subject will be detailed in the next paragraph.

6. Data for an Economic Analysis.

(1) Since many public projects compete for financing, while public resources are not limitless, one of the basic oriteria for public investment in transportation facilities is a measure of the benefits that can be anticipated as a result of the investment; - the greater the benefits, the more justifiable the investment may become.

A transportation economical analysis (or 'Feasibility Study' as it is sometimes called) is, in essence, a comparison between the monetary-value of the benefits to the public against the cost of improving the transportation system.

Most of the input data for an economic analysis is straightforward quantitatively defined values, such as the cost of implementing the recommended transportation plan. The benefits, however, are more difficult to define, since they also include the value of time saved by the public when using the improved transportation system (or the value of the time - loss if the system is not improved).

It is not within the scope of this research to discuss feasibility studies (a subject which is extensively covered by technical literature, examples of which are detailed in the 'General Reading' part of the References), but rather to show that the most essential part of the benefit analysis, that of time save - or loss - may directly be derived from the synthesis procedure.

(2) Such an example is presented here, as follows:-

(a) It is first assumed that Freeways are not planned for Tel-Aviv 1985, and that all the projected traffic burden will have to be carried by the Arterial network only.

Since the projected Kilometrage for the Freeway plus Arterial networks for 1985 is 8,189,000 veh.km., it follows that at peak-hour, assuming again 10%, it will be 818,900 veh.km.

(b) If no improvements are planned for the existing Arterial network, with a length of 430 km. of free-lanes, it may be concluded that the expected average volume per 1-km. lane will be -

$$q = \frac{818,900}{430} = 1,900 \text{ vph.};$$

By refering to the Speed-Volume relationship of Arterials, in Fig. 5.5, it can immediately be concluded that such an assumption is not possible at all, since the maximum possible flow is about 1,000 vph. only.

The only possibility, within the first assumption (a) is, therefore, that the Arterial network must be improved by adding more lanes.

(c) By refering to the 'Density' procedure for computing the necessary road length of Arterials, the Kilometrage density is -

$$I = \frac{8,189,000}{189.4} = 43,200 \ ;$$

And by Fig. 3.8 the appropriate Arterial road density is 3.6 km/sq.km. The necessary Arterial length is, therefore -

$$L = 189.4 \times 3.6 = 680 \text{ km.} \ ;$$

Assuming a width of 2.5 free-lanes per average road, the total lane-length would then be - 1,700 km.

The expected average volume per 1-km of lane is, therefore-

$$q = \frac{818,900}{1,700} = 481 \text{ vph.}$$

(d) By refering to the Speed-Volume relationship for Tel-Aviv 1985, in Fig. 5.5, it may be concluded that the expected average speed will be 34.3 kph.

The total travel-time on such a network at peak-hour will then be -

$$t_p = \frac{818,900}{34.3} = 23,850 \text{ veh. hours.}$$

(e) If it is assumed, on the other hand, that the recommended road system be built, namely 326 km. of Freeway lanes and 608 - 430 = = 178 km. of Arterial lanes, the expected average speed on this network will be 38.9 kph, where the peak-hour Kilometrage and speed for the Freeway network is 342,200 and 61.0, and for the Arterial network is 476,700 and 31.0 respectively(in Tab. 5.4). The total travel-time on this network at peak-hour will then be -

$$t_p = \frac{818,900}{38.9} = 21,010 \text{ veh. hours.}$$

(f) It may be concluded at this stage that two alternatives are now available for evaluation:-

(I) Adding 1,700 - 430 = 1,270 km. of Arterial lanes for the target year, with an average speed of 34.3 kph;

(II) Adding 326 km. of Freeway lanes + 178 km. of Arterial lanes for the target year, with an average speed of 38.9 kph.

While it is not yet clear how 1,270 km of Arterial lanes may practically be added to the Tel-Aviv urban area, especially where they are mostly needed, it may be assumed, for the sake of argument, that it is feasible.

The two sets of costs for the two alternative plans may then be calculated by the standard procedures.

(g) However, in regard to the time-saving benefits resulting from alternative (II), it amounts to:-

t_s = 23,850 - 21,010 = 2,840 veh, hr. per peak-hour in 1985, or 1 million hours per one year (of 350 days), or equivalent to a saving of about 120 years of time per 1 peak-hour per day.

This saving - or loss, depending on which alternative is chosen - has now to be multiplied by the average number of persons per veh.km. (since a bus, for example, carries several dozens of people per veh.km. at peak-hour), as well as computed separately for each hour of the day, in accordance with the volume distribution over the hours of the day.

Moreover, since the Kilometrage will gradually increase from base-year to target-year (usually along a Logistic curve) the times should be accumulated for that period.

Extremely high values of time savings - or losses - incurred to the public may thus be easily computed and evaluated.

(h) By defining the cost of such time (usually productive - time is considered, which amounts to about a third only of the total time), a monetary value of the time benefits is thus produced, which is an essential part of the total benefits versus the total costs comparisons and analysis.

It may be concluded, therefore, that the proposed procedure, of analytically synthesizing a comprehensive vehicular Transportation Study, may also produce much of the required information for a macro first-approximation economic analysis of the transportation system, whether for the justification of improving in principle the existing network for the projected and expected traffic demands, or for the evaluation of various alternatives of road networks plans, with different proportions of the road categories.

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS.

In this research an endeavor has been made to analyze whether a comprehensive transportation study may fully be synthesized by analytically applying a limited number of basic area parameters, with sufficient accuracy for a first approximation evaluation.

It is believed that this endeavor has been successful.

While carrying out this research several general as well as specific conclusions have come to light, which merit a more thorough discussion and illumination, as follows:-

1. The need for Standard Definitions.

It has been noted time and again that the various transportation studies have frequently been based on different definitions and/or procedures.

Moreover, even when several studies started from the same definitions, the end-results, as presented in the final reports, differed to a considerable extent, thus impeding a comparative analysis.

An even more difficult problem has been the frequently total lack of some essential information in several of the reports, such as the assigned Kilometrage on a specific category of road, average number of lanes, speeds, etc.

It is true that most of the latest transportation studies in the United States adhere to the strict standards defined and imposed by the Bureau of Public Roads, particularly if Federal Aid is involved. However, even such study reports do not always present the basic parameters or results in their full and detailed form.

Moreover, since no international standard has been approved in this field, nor even recommended, the transportation studies from other parts of the world may differ from each other to a considerable extent.

It should be noted at this stage that it is the part of defining the basic components, or building-blocks, of such studies that is so essential, and not the procedures.

In other words, procedures may vary from country to country, or even from town to town within the same country, according to personal believes and preferences of the study director, but this will have no practical effect as long as the same basic definitions are used in, and the same results are derived from , such studies.

Particular attention should be given to the definition of the metropolitan area, vehicle types, trips and Kilometrage (inter-zonal and intra-zonal), categories of roads and networks, speed-volume relationships, and other such closely related subjects.

The urgent call for establishing an international code of standards has been put forward on may occasions, but as yet no practical results have emerged.

It may be concluded, therefore, that such internationally-approved standards are urgently needed and that an international organization, such as the Transport Division of the U.N. or the International Road Federation, may be the most suitable agency to initiate it; and the sooner the better.

2. Applications and further development of the proposed procedure.

The procedure developed in this research may practically be applied not only for fully synthesizing transportation data for a given metropolitan area, but also for shortening many procedural steps currently in use.

For example, if detailed information on the volume counts in an urban area is available - by the multiple screen line method, etc.- then the Kilometrage and its distribution in the area may be computed.

Moreover, by the Kilometrage Density or the 'IN' procedure, the road networks may then be analyzed and evaluated. Thus, one actual survey, such as volume counts, may be used as a stepping-stone for a better and more accurate calibration of the many relationships derived from this research.

In other words, if just a few basic traffic patterns are known for an urban area, together with the knowledge of the Population - Motorization - Area, all other relevant traffic and transportation data may then analytically be derived, and checked, by refering to the relationships detailed in this report.

Furthermore, by recognizing the vehicles as a new, separate, 'population' in an urban area, many new and novel methods for carrying-out comprehensive transportation studies may be possible.

One such possibility is the method which may be defined by 'Aerial Sampling': - If aerial photographs of an urban area are taken at peak hour, and if the speeds on the networks are derived from the same photographs (by double-exposure at a specific time-interval), or from any other method, automatic or by observations, then the following comprehensive information may be defined for the area:-

(a) A full inventory of the road network, including categories of roads and the number of free lanes for each category;

(b) The INstant number of vehicles on the network, as well as their distribution on its parts;

(c) Speed-Volume-Spacing relationships for the various categories of roads, as well as the average speed for the whole network;

(d) The total Kilometrage as well as its distribution on the road network at the critical hour.

If hourly automatic volume counts are also taken at several key-points on the major sections of the road network, thus defining the hourly variations of the traffic on the network, then enough information is at hand for fully defining the traffic patterns and characteristics in a town during an average day.

The aerial photography need not necessarily cover all the area, since a statistical sample may be quite adequate for deriving the traffic data within any desired level of accuracy.

At this stage it is of interest to refer back to the Research Results Digest No. 27 (NCHRP) mentioned in the Introduction chapter of this Dissertation (page 3) and repeat the third important conclusion and recommendation published there:-

"(3) Research and experimentation should be encouraged in the use of aerial photography, on a sampling basis, for counting vehicle traffic on urban street systems".

Not only is this recommendation timely, and in accordance with the basic approach which underlines this Dissertation, but it is believed that the proposed 'IN' Model and procedure may be integrated in a promising way with this recommendation, with the interesting possibilities of developing an entirely new method for conduction a comprehensive transportation study.

At this stage it may be argued that the proposed procedure does not answer at all several crucial questions, such as:- defining the interaction between land-use and traffic, or socioeconomic relationships, for forecasting trip generation and attraction for a target-year; defining or calibrating a distribution traffic model; assigning the O-D matrix on a road network by minute summing-up of individual trips; and so on.

It is true that the new procedure does not answer these questions. However, all current traffic models and procedures are based on the fundamental assumption that traffic patterns in a town are predictable, since traffic behaviour is basically the same in each and every town; - it is only the minor local factors which are in need for defining for the purpose of calibrating the basic model.

On the other hand, all the numerous surveys which are conducted today in a comprehensive study are just for that purpose, namely for calibrating the already adopted model. Moreover, the end-result of the

current lengthy comprehensive procedures - notwithstanding which one of the many traffic models is used - is always the Kilometrage distribution assigned to the road network.

In other words, it is the end-result of the current procedures which is important for the planning stage, and not the type or method of the procedure as such.

Therefore, if the same final results may be derived, within acceptable levels of accuracy, by the application of the new proposed procedure, and if the purpose is for a first approximation evaluation of the existing - or projected - traffic patterns and road networks, then the proposed procedure may be considered as a replacement for the current methods.

Moreover, if the same basic total Kilometrage as defined by the comprehensive procedure, after 2-3 years of hard work, may be derived by the new procedure after about 10-minutes time of juggling with a small slide-rule, and within an accuracy of plus-minus a few per cent, then the new procedure has its own value, even if only by complimenting the current comprehensive procedures.

It is true that the distribution phase of the Kilometrage over the area, by any one of the methods presented in this Dissertation, and the derivation of the road network components by the Kilometrage Density or the 'IN' procedures, may take another few hours of work, but even that duration is less then negligible when compared to the time-and-effort expended while using the standard procedures.

It is believed, therefore, that the new procedure may be used not only as a practical tool for traffic analysis, but it may also be further developed to achieve higher levels of applicability and accuracy.

3. The need for further analysis on the road networks.

Road network analysis is still in its infancy. Just a few years ago all effort were directed at road sections and junctions analysis, by the ingenious application of many mathematical tools, such as the theories of probability and queuing, or leaning heavily on physical analogies such as fluid kinematics. Even the classical 'Highway Capacity Manual - 1965' is devoted exclusively to road-sections and junctions analysis, with no mention of network analysis.

The first steps in road network analysis have lately been taken by mathematicians and Operation-Research theoreticians, although no practical results for immediate use are yet available for Town-Planners or City-Engineers.

The only comprehensive analysis carried-out to date, from a traffic operation point of view, as well as with several practical conclusions for

road network planning, seems to be the latest published work by Prof. R.J. Smeed, entitled 'The effect of the design of road network on the intensity of traffic movement in different parts of a town with special reference to the effects of ring roads'. Although this work is mainly concerned with idealized models for the central areas of cities, it arrives at several tentative conclusions which are of particular interest for the planning of comprehensive networks of roads, as follows (from Prof. Smeed's paper to the 10-th International Study Week in Traffic and Safety Engineering, Rotterdam 1970):-

> "Two of the common desiderata in urban road planning are a minimum total travel distance and a small value for the distance travelled per unit area in the town center for any likely origin-destination pattern.
>
> The analysis suggests that for a large range or origin-destination patterns both these objectives may, to a considerable extent, be achieved by arranging for:
>
> (a) A ring road around the central area on which speeds are fast relative to speeds within the area;
>
> (b) Radial roads - unconnected with one another - leading from near the town center to the ring road;
>
> (c) A series of ring roads beyond the first together with a series of radial roads leading outwards from the innermost ring roads. The ring roads should be designed so that the average speed on any one of them is apperciably faster than on the radial roads leading into it from the direction of the town center.
>
> The first and third arrangements may, however, often be enough to achieve the objectives desired, especially if the road system does not encourage traffic to travel to the centre of the city.
>
> ...Since these tentative conclusions, if valid, could sometimes be used to effect large desirable changes in the pattern of traffic in towns, they should be investigated further both by calculations using real origin-destination patterns and real road systems and also by the measurements of traffic patterns in real towns."

Two principle conclusions may, thus, be derived fron this work:- (1) Road network analysis is still a new frontier, where much further work has yet to be done; (2) Road network analysis may be considered as an essential backbone for any Town - or even Regional - Planning, since it may not only affect the spatial structure of the urban area, but also strongly influence the patterns of the dynamic life within it.

It may be concluded, therefore, that this Dissertation has presented only one aspect of the overall problem, namely that of rapidly synthesizing transportation and network data for base-year, as well as for target-year, on the basis of current planning-philosophy. Network analysis, on the other hand, opens new and far reaching possibilities for defining new network-structures which may substantially reduce the expected amount of travel in cities, as well as organize existing patterns in more efficient ways.

Much work is still ahead. It is believed, therefore, that by integrating the proposed synthesis procedure developed in this research - which is based on empirical relationships intermingled with theoretical considerations - together with the purely mathematical analysis of road networks, such as the one mentioned above, may pave the way for a better understanding of the traffic patterns and behaviour in the cities.

Moreover, it is hoped that this integration may also lead to the development of new, practical, and rapid procedures for not only analytically synthesizing the detailed traffic patterns, but also for a better planning of the road networks and the traffic conditions in the modern cities of today and of tomorrow.

* * *

P O S T S C R I P T

1. The Jerusalem Transportation Study.

While writing the last chapter of this report an additional transportation study has been made available to the author, thus enabling him to close this report with one more example.

The study is that of united Jerusalem, which was begun in 1968 and is now in its final stages of completion. The author is indebted to the director of the study, who made available the study's results even before the publication of the final report.

The vehicular part of the transportation study of Jerusalem has been carried out by the novel method of interviewing samples of drivers at multiple screen-lines and then expanding the results by screen-line volume counts. Thus, the lengthy and expensive Home-Interview survey was by-passed. (Public - transport passengers were interviewed at the bus-stops). Further analysis of the generated and attracted trips has proven the validity of this method, by supplying accurate results comparable to similar results derived in the Tel-Aviv study by the Home-Interview method. The only limitation of the multiple screen-line method is the lack of knowledge on intrazonal vehicle trips which, naturely, were not interviewed at the borders of the traffic zones. (Socioeconomic data for the zones was obtained by another survey).

The Origin-Destination survey had covered all classes of vehicles, including motorcycles, but for reasons of comparison, the results have been deleted here to include passenger cars and commercial vehicles only.

The study covered the metropolitan area of Jerusalem, encompassing various significant parts, such as the (1) Western City; (2) Eastern City; (3) the Close Metropolitan Area; and (4) the Regional Metropolitan Area, including the neighbouring towns of Bethlehem and Ramalla.

Since the Regional Metropolitan Area is very hilly and quite empty of any continuous urbanization, the following data is for the Close Metropolitan Area, although even that part, around the city proper , is quite sparse of population and traffic.

It is of interest to note that the Jerusalem study has supplied an additional evidence to one of the fundamental assumptions of this thesis, namely that vehicles may constitute a separate population group in the city, with its own characteristic and inherent behaviour. This was proved in a rather interesting manner, as follows.

Table 6.1

Synthesizing the Transportation Study of Jerusalem - 1968

Population : 278,426
Motorization: 3.4 %
Area, Sq.Km.: 110

Step	Synthesized				Given		
	Factor	Result	T	K	Result	T	K
1	3.4	9,520			9,521		
2	8.0						
3			76,000			63,172	
4		5.9					
5		3.8					
6				289,000			-
7	36.0	3,420			3,075		
8 a							
8 b	40.5	30,800					
8			30,800			27,616	
9				117,000			-
10							
11							
12							
13 a	6.3	6,700					
13 b	2.0	19,000					
13			12,850			3,434	
14				48,900			-
15			119,650			100,122	
16				454,900			415,000

Difference in Trips: + 19.5 %
Difference in Kmt. : + 9.6 %

Jerusalem had been divided for twenty years, with development taking two extreme directions:- In the western Israeli part of the city with a population of 210,000 and a motorization of 4.1%, and in the eastern Arab part of the city, with 69,000 and 1.3% respectively. Nevertheless, and in spite of the extreme differences in the basic conditions existing in the two parts of the city and the wide gap dividing them economically, traditionally, psychologically, sociologically, etc., just one year after the city was reunited, the very limited number of vehicles in the eastern part of Jerusalem displayed exactly the same basic travel patterns as the vehicles in the western part - patterns characteristic of a combined and integrated vehicle-population.

Moreover, the two most important parameters - Trip Rate and Trip Length - were practically the same in both parts of the united city (though the O-D may differ). In other words, irrespective of the identity (or race or nationality) of the driver, the vehicles as such behave as equal units of an integrated vehicle population, and their behaviour may be explained by the three basic parameters of the area, namely - Population, Motorization, and Area.

The results of the synthesis are detailed in the following table and are compared with the given actual data.

The synthesis procedure is an accurate replica, stagewise, of the procedure detailed in Chapter 2, Par. 3. As can be seen, although the actual trips are somewhat under-estimated (since they do not include intra-zonal trips), the Kilometrage is basically the same, with a difference of 9.6 per cent only, namely within the acceptable levels of accuracy.

2. An additional example of a Simplified Method.

The search for simplified methods for traffic analysis goes on now all over the world. At the last stages of analysis in this Dissertation the author received an additional example for such a method, as detailed in Research Result Digest No. 26 (1971) of the National Cooperative Highway Research Program (NCHRP), USA, on the subject of 'Improved Criteria for Timing Traffic Signal Systems in Urban Networks'.

The major emphasis in this project was - "on developing reliable and inexpensive methods of improving traffic operations through simple modifications of fixed-time signal settings ...This project was heavily application-oriented, and conscious efforts were made to emphasize investigation of improved traffic control techniques that could be used immediately and widely, without expending large sums of money".

Ten basic traffic signal timing plans were employed in various combinations, from simple and direct ones and up to very complex and sophisticated procedures.

The findings which have direct bearing on the results presented in this Dissertation are:- "The research findings indicate that improvements in operation produced by the relatively simple methods are equal, or nearly equal, to results produced by complex methods...These (complex) methods all involve the use of complicated computer programs, the understanding of which requires investment in a substantial intensive study and consultation period...In applying the so-called simple methods, there is a minimum degree of reliance on the computer, and the computer programs that are used are uncomplicated and easy to understand and operate ... It has been found that these so-called simple methods, when applied together properly result in highly effective strategic plans for signal operation".

Thus, one of the basic hypotheses assumed in this Dissertation, that traffic patterns may adequately be represented, or planned, by simple methods rather than by applying complex ones, seems to be indicated again by research, even though for signal settings only.

In other words, it has been proven that simple procedures may be applied with adequate accuracy to represet the behaviour of traffic flow at the junction points of road networks.

It is believed, therefore, that the above additional example is worth of mentioning when considering the acute problem of searching for new and simple methods for traffic analysis.

* * *

R E F E R E N C E S

Chapter 1.

1.1 - "Tel-Aviv - Yafo Transportation Master Plan", Kolin & Zahavi, 1969.

1.2 - "Traffic Engineering Handbook", Institute of Traffic Engineers, 1965, page 149.

1.3 - "Mathematical Theories of Traffic Flow", Frank A. Haight, Academic Press, 1963.

1.4 - "An Introduction to Traffic Flow Theory", Research Board Special Report 79, 1964.

1.5 - "The Theory of Road Traffic Flow", Winifred D. Ashton, Methuen & Co. 1966.

1.6 - "Traffic Flow Theory & Control", Donald R. Drew, McGraw-Hill 1968.

1.7 - Proceedings of the 1-2-3-4 International Symposiums on the Theory of Traffic Flow.

1.8 - "Highway Capacity Manual - 1965", Highway Research Board, 1965.

1.9 - "Traffic Studies and Urban Congestion", Prof. R.J. Smeed, Jour. of Transport Economics and Policy, 1968.

1.10 - "The Mechanism of a Road Network", J.W.Godfrey, Traffic Eng. & Cont. November 1969.

1.11 - "Some Theoretical Aspects of Road Research", J.G. Wardrop, Road Paper 36, Proc. Inst. Civ. Engrs., 1952.

1.12 - "Traffic Engineering Practice", Edited by E. Davies, E. & F.N. Spon, 1968, Page 65.

Chapter 2.

2.1 - "Future Highways and Urban Growth", Wilbur Smith and Associates, The Automobile Manufacturers Association, 1961.

2.2 - "Transportation and Parking for Tomorrow's Cities", Wilbur Smith and Assoc., 1966.

2.3 - "Principles and Techniques of Predicting Future Demand for Urban Area Transportation", by Martin, Nemmott & Bone, M.I.T. report 3.

Chapter 3.

3.1 - "System Considerations for Urban Freeways", Inst. Traffic Engrs. 1967.

3.2 - "Transportation Systems in the Future Development of Metropolitan Areas, J.E. Leisch, HRB Record No. 293, page 99.

3.3 - "System Considerations for Urban Arterial Streets", Inst. Traffic Engrs., 1969.

Chapter 4.

4.1 - J.Q. Stewart: (1) 'Demographic Graviatation: Evidence and Applications', 1948;

(2) 'Potential of Population and its Relationship to Marketing', 1950.

(3) 'The Development of Social Physics', 1950.

4.2 - "Human Behaviour and the Principle of Least Effort", G.K.Zipf, 1949.

4.3 - "Highway Traffic Estimation" Schmidt & Campbell, The Eno Foundation for Highway Traffic Control, 1956.

4.4 - 'Intervening Opportunities: A Theory Relating Mobility and Distance', S.A. Stouffer, American Sociological Review, 1940.

4.5 - 'The Effect of Distance in the Theory of Traffic Generation Poles', Prof. L.H.J. Angenot, De Ingenieur, The Netherlands, 1961.

4.6 - 'Factors Affecting the Amount of Travel', J.C. Tanner, Road Research Laboratory, 1961.

4.7 - 'Description and Shortcomings of Some Urban Road Traffic Models', D.B. Fairthorne, Operation Research Quarterly, 1964.

4.8 - 'A Field Theory of Land Use and the Movement of People', Robert T. Howe, Doctorate's Thesis, Purdue University, 1959.

4.9 - 'The Inter-Action of Traffic Generation and Land Use in Amsterdam', M. 't-Hart, H.M. Goudappel & Alan Black, The Seventh Inter. Study Week in Traffic Engineering, London, 1964.

4.10 - 'From Land Use to Traffic Volumes: The Amsterdam Study', M. 't Hart & Alan Black, Town Planning Department, Amsterdam.

4.11 - 'Urban Population Densities: Structure and Change', Berry, Simmons & Tennant, "Population Geography: A Reader", Edited by Demko, Rose & Schnell, MacGraw-Hill, 1970.

Chapter 5.

5.1 - 'The Maximum Number of Road Vehicles that can usefully Enter an Urban Center', Prof. R.J. Smeed, Eighth International Study Week in Traffic Engineering, Barcelona, 1966.

5.2 - 'Road Capacity of City Centers', Prof. R.J. Smeed, Traffic Engr. & Control, November 1966.

5.3 - "A Study of Road Traffic Crossing the Cordons around the Central Areas of Eight Towns", Munt & Webster, Road Research Laboratory, Report LR 209, 1968.

General Reading:

A. Urban Geography, City Structure, and Potential Fields.

1. - "Models in Geography", Edited by Chorley & Haggett, Methuen 1967.
2. - "Methods of Regional Analysis: An Introduction to Regional Science", W. Isard, The M.I.T. Press, 1960.
3. - "Location and Space-Economy" W. Isard, The M.I.T. Press, 1956.
4. - "Population Geography: A Reader", Edited by Demki et al, MacGraw, 1970.
5. - "Readings in Urban Geography", Edited by Mayer & Kohn, The University of Chicago Press, 1960.
6. - "Urban Research Methods", Edited by Gibbs, Van Nostrand 1961.
7. - "Urban Land Use Planning", F.S. Chapin, Univ. of Illinois Press 1963.
8. - "Regional Development and Planning", Edited by Friedman & Alonso, The M.I.T. Press, 1964.
9. - "Models of Man, Social and Rational", H.A. Simon, Wiley 1957.
10. - "Cities and Society", Edited by Hatt & Reiss, The Free Press of Glenco, 1963.
11. - "A Communication Theory of Urban Growth", R.L. Meier, M.I.T. Press 1962.
12. - "The Economics of Location", August Losch, Yale University Press 1954.
13. - "The Heart of our Cities", Victor Gruen, Simon and Schuster, 1964.
14. - "Planning for Man and Motor", Paul Ritter, Pergamon Press, 1964.
15. - "The Highway and the City", Lewis Mumford, Harcourt, Brace & Worlds 1963.
16. - "The Death and Life of Great American Cities", Jane Jacobs, Penguin 1964.

B. Traffic Patterns and Models.

1. Highway Research Board Publications:-

Bulletins: 119 - Factors Influencing Travel Patterns, 1956;
203 - Travel Characteristics in Urban Areas, 1958;
224 - Trip Characteristics and Traffic Assignment, 1959;
253 - Traffic Origin - Destination Studies, 1960;
297 - Forecasting Highway Trips, 1961;
347 - Trip Characteristics and Traffic Assignment, 1962;

Records: 38 - Travel Forecasting, 1963;
41 - Origin and Destination Techniques and Evaluation, 1963:
88 - Travel Patterns, 1965;
102 - Urban Transportation Planning Techniques and Concepts, 1965;
114 - Origin and Destination: Methods and Evaluation, 1966;
205 - Origin and Destination Characteristics, 1967;
283 - Travel Factors and Travel Models, 1969;
309 - Transportation Analysis: Past and Prospects, 1970;
322 - Travel Analysis, 1970.

2. "A Comparative Evaluation of Trip Distribution Procedures", Heanue & Pyers. 'Public Roads', USA, June 1966.
3. "Principles and Techniques of Predicting Future Demand for Urban Area Transportation", Martin et al. The M.I.T. Press 1965.
4. "Schems of Road Networks in Urban Areas" Sixth Inter. Study Week, 1962.
5. "Studies of the Central Business District and Urban Freeway Development", Horwood & Boyce, University of Washington Press 1959.
6. "Land-Use and Traffic Models", Special Issue, Journal of the American Institute of Planners, May, 1959.
7. "An Analysis of Urban Travel Demands", Oi & Shuldiner, Northwestern University Press, 1962.
8. "Urban Survival & Traffic", Symposium 1961, Edited by Williams, Spon 1962.
9. "Research on Road Traffic", Her Majesty's Stationary Office, 1965.
10. "People and Cities", The British Road Federation, 1964.
11. "The Urban Transportation Problem", Meyer et al, Harvard Univ. Press 1965.
12. "Traffic System Analysis for Engineers and Planners", Wohl & Martin, McGraw - Hill 1967.
13. "Analytical Transport Planning", Lane et al, Duckworth 1971.

C. Economics of Road Transport.

1. Ref. B-11, B-12.
2. "The Economics of Highway Planning:, Winch, Univ. of Toronto Press 1963.
3. "Public Enterprise Economics & Transport Problems", Kuhn, University of California Press 1962.
4. "Highway and Economic and Social Changes", U.S. Burue of Public Roads 1964.
5. "Highway Benefits", Mohring & Harwitz, Northwestern Univ. Press 1962.
6. Highway Research Board Publications: Such as: Bulletins - 306,320, Records:- 12,77,148,180,285,293,305; NCHRP Reports: 96.

* * *

APPENDICES

Appendix 1

Speed - Spacing Relationships

(Fig. 1.1)

Speed(kph)	Spacing(m)
Curve 1	
84.5	114
84.0	105
83.0	83
80.5	67
75.0	53
67.0	42
56.0	31
51.0	27
Curve 2	
83.0	415
82.8	208
81.5	135
81.0	101
79.0	80
75.0	62
70.5	51
65.5	41
Curve 3	
74.0	80
64.0	40
48.0	30
40.0	27
32.0	24
19.4	20
8.0	16
Curve 4	
72.0	80
63.0	40
53.0	27
48.0	24
40.0	20
32.0	18
24.0	16
21.0	15
Curve 5	
80.0	250
79.0	196
75.5	126
72.5	91
69.5	70
65.5	54
61.7	44

Speed(kph)	Spacing (m)
Curve 6	
56.0	54
52.0	45
48.0	40
37.0	27
31.0	20
24.0	16
19.3	13.3
14.5	11.5
11.0	10
8.0	9
Curve 7	
60.0	1,000
48.0	65
39.0	32
32.0	26
16.0	16
Curve 8	
56.0	1,000
48.0	80
43.0	40
35.0	26
29.0	20
21.0	16
15.0	13
8.0	11.5
Curve 9	
55.0	1,000
53.0	263
50.0	125
48.0	80
45.0	56
43.0	47
40.0	40
39.0	39
Curve 10	
36.0	69
34.0	58
32.0	50
30.0	43.5
28.0	38
26.0	33
24.0	28.5
22.0	24.5
20.0	21

Speed (kph)	Spacing(m)
Curve 11	
35	175
34	85
32	53
31	38
29	29
28	23
27	19
Curve 12	
34	1,000
32	65
30	32
26	22
24	16
19	11
16	8
11	6.5
Curve 13	
30	100
28	78
26	61
24	50
22	40
20	33
18	27
Curve 14	
34.5	285
31.2	130
27.5	76
24.1	50
19.0	31.5
16.1	24.5
12.4	17.2
8.0	10.3
Curve 15	
29.8	300
29.3	147
29.0	97
27.7	69
24.5	49
22.5	41
17.7	29
11.0	18
Curve 16	
24.4	45
17.8	30
13.8	22
10.8	18
8.2	15
6.4	12.8
4.8	11.2
3.5	9.9

Appendix 2

A Computed Example of the Speed - Volume - Spacing Relationship

(Fig. 1.2)

Speed (kph)	Curve d/e-1		Curve d/e-2	
	Volume	Spacing	Volume	Spacing
50	1,910	26.2	1,910	26.2
45	2,010	22.4	1,970	22.8
40	2,080	19.2	2,000	20.0
35	2,140	16.3	2,010	17.4
30	2,170	13.8	1,950	15.4
25	2,200	11.3	1,760	14.2
20	2,180	9.2	1,000	20.0
15	2,150	7.0	620	24.2
10	2,080	4.8	360	27.8
5	1,860	2.7	150	33.4
2.5	1,500	1.7	80	31.3
1	1,000	1.0	20	(50.0)

Appendix 3

Computing Factor 'C'

(Fig. 1.5)

Freeway '2'		Freeway '1'		Parkway		Urban		C.B.D.	
Speed	Spacing	Spacing	'C'	Spacing	'C'	Spacing	'C'	Spacing	'C'
65	45	92	2.04						
60	36	58	1.61						
55	29	42.5	1.46						
50	24	34	1.42	120	5.00				
45	21	27.2	1.30	54	2.57				
40	19	23	1.21	36	1.90				
38	18	21.6	1.20	31.8	1.77	137	7.60		
35	17	20.2	1.19	27.5	1.62	79	4.65		
30	15.5	18	1.16	22.5	1.45	41.5	2.67	126	8.11
25	14	15.8	1.13	19	1.36	27	1.93	54	3.86
20	12	13.8	1.15	16	1.33	20	1.67	34	2.84
15	10.5	11.9	1.13	13	1.23	15.8	1.50	23	2.19
10	9	9.8	1.09	10.5	1.17	12	1.33	15	1.67
5	7.7	7.8	1.01	8	1.04	9	1.17	10	1.30
2.5	7	7.4	1.05	7.5	1.07	8	1.14	8	1.14

Appendix 4

The Study Towns

1. Adelaide, Australia - "Metropolitan Adelaide Transportation Study" By De Leuw, Cather and Co., Rankine and Hill, Alan M. Voorhees and Assoc. Inc.
2. Amsterdam, Holland - Information supplied by ir. M. 't-Hart, of the Dienst der Publieke Werken, Amsterdam.
3. Athens, Greece - "Athens Basin Transportation Survey and Study", by Wilbur Amith and Associates (W-S & Assoc.).
4. Baltimore, USA - "Baltimore Metropolitan Area Transportation Study", by W-S & Assoc.
5. Baton Rouge, USA - "Baton Rouge Metropolitan Area Transportation Study", by W-S & Assoc.
6. Belfast, North Ireland - "Travel in Belfast", by R. Travers Morgan & Partners.
7. Birmingham, UK - by Freeman, Fox, W-S & Assoc.
8. Bombay, India - "Bombay Traffic and Transportation Study", by W-S & Assoc.
9. Brisbane, Australia - by W-S & Assoc.
10. Charleston, USA - "Charleston Area Transportation Study", by W-S & Assoc.
11. Chattanooga, USA - "Chattanooga Metropolitan Area Transportation Study," by W-S & Assoc.
12. Chicago, USA - "Chicago Area Transportation Study", by a local team.
13. Clumbia, USA - "Columbia Area Transportation Study", by W-S & Assoc.
14. Copenhagen, Denmark - "Greater Copenhagen Regional Transportation Study", by Freeman, Fox, W-S & Assoc.
15. Dundee, Scotland - "Dundee Transportation Study", by Freeman, Fox, W-S & Assoc.
16. Helsinki, Finland - by W-S & Assoc. and Pentti Polvinen Consulting Engrs.
17. Kingston upon Hull, UK - by Freeman, Fox, W-S & Assoc.
18. Knoxville, USA - "Knoxville Metropolitan Area Transportation Study", by W-S & Assoc.
19. London, UK - "London Traffic Survey", by Freeman, Fox, W-S & Assoc.

20. Melbourne, Australia - by W-S & Assoc.

21. Monroe, USA - "Monroe Metropolitan Area Transportation Study" by W-S & Assoc.

22. Orlando, USA - by W-S & Assoc.

23. Pittsburgh, USA - "Pittsburgh Area Transportation Study", by a local team.

24. Ponce, Puerto Rico - "Ponce Metropolitan Area Transportation Study", by W-S & Assoc. and Padilla & Gracia.

25. Pulaski, USA - "Pulaski Area Transportation Study", by W-S & Assoc.

26. Rapid City, USA - "Rapid City Metropolitan Area Transportation Study, by W-S & Assoc.

27. Richmond, USA - "Richmond Regional Area Transportation Study". W-S & Assoc.

28. Rotterdam, Holland - "Land Use and Transportation Study", by Verkeersdienst Rotterdam.

29. Sioux Falls, USA - "Sioux Falls Metropolitan Area Transportation Study", by W-S & Assoc.

30. Tel-Aviv, Israel - "Tel-Aviv - Yafo Transportation Master-Plan", by Kolin & Zahavi.

31. Tucson, USA - "Tucson Area Transportation Study" by a local team.

32. West Midlands, UK - "West Midlands Transportation Study" by Freeman Fox, W-S & Assoc.

33. Winston Salem, USA - "Winston-Salem Area Transportation Study", by W-S & Assoc.

34. Zurich, Switzerland - Information supplied by H.B. Barbe, Dipl. Ing.

APPENDIX 5

SYNTHESIZING THE TRANSPORTATION STUDIES OF THE STUDY-TOWNS

Description of the Tables

A - Factor for Synthesis

B - Result)
C - Trips (ooo)) Synthesized
D - Kilometrage (ooo))

E - Data)
F - Trips (ooo)) Given
G - Kilometrage (ooo))

a - Population
b - Motorization of Pass. Cars, %.
c - Area, in Sq.Km.

1 - Number of Pass. Cars
2 - Trip Factor of Pass. Cars
3 - Trips of Pass. Cars
4 - Radius of Study Area, km.
5 - Average Trip Length, km.
6 - Kilometrage of Pass. Cars
7 - Number of Commercial Vehicles
8 - Trips of Comm. Veh. (a)
9 - Trips of Comm. Veh. (b)
10 - Trips of Comm. Veh., average
11 - Kilometrage of Comm. Veh.
12 - Taxi Trips
13 - Average Trip Length of Taxis
14 - Kilometrage of Taxis
15 - External Trips (a)
16 - External Trips (b)
17 - External Trips, average
18 - External Kilometrage

19 - Total Daily Trips
20 - Total Daily Kilometrage

21 - Difference between Given and Synthesized Trips, %.
22 - Difference between Given and Synthesized Kilometrage, %.

1. ADELAIDE - 1965

	A	B	C	D	E	F	G
a		723,000					
b		27.5					
c		1,120					
1	27.5	199,000			198,800		
2		3.3					
3			657				
4		18.8					
5		7.0					
6				4,600			
7	13.8	27,400					
8		200,000					
9	21.6	142,000					
10			171				
11				1,200			
12							
13							
14							
15	16.0	132,500					
16	0.53	105,500					
17			119				
18				833			
19			947			1,027.5	
20				6,633			6,625
21		- 7.8					
22		+ 0.1					

1. ADELAIDE - 1986

	A	B	C	D	E	F	G
a		1,159,000					
b		38.3					
c		1,120					
1		443,000			443,000		
2		3.5					
3			1,550				
4		18.8					
5		8.6					
6				13,330			
7	13.0	57,500					
8		425,000					
9	13.4	208,000					
10			316.5				
11				2,720			
12							
13							
14							
15	17.0	317,000					
16	0.53	235,000					
17			276				
18				2,370			
19			2,142.5			2,059.9	
20				18,420			15,335
21		+ 4.0					
22		+ 20.1					

3. A T H E N S - 1962

	A	B	C	D	E	F	G
a		1,900,000					
b		2.1					
c		448					
1	2.1	39,000			39,000		
2		8.0			7.7		
3			312.0			303.0	
4		12.0					
5		6.0			5.6		
6				1,870.0			
7	47.5	18,500			23,000		
8		123,000					
9	41.5	130,000					
10			126.5			127.0	
11				760.0			
12	33.3		106.5			104.0	
13	3.0						
14				320.0			
15	4.7	20,600					
16	0.77	30,000					
17			25.3			22.3	
18				152.0			
19			570.3			556.3	
20				3,102.0			3,100.0
21		+ 2.5					
22		0.0					

3. A T H E N S - 1980

	A	B	C	D	E	F	G
a		2,800,000					
b		9.7					
o		448					
1	9.7	270,000			270,000		
2		3.8			4.5		
3			1,025.0			1,208.6	
4		12.0					
5		7.1			6.5		
6				7,260.0			
7	19.0	51,300			80,000(1)		
8		385,000					
9	36.0	369,000					
10			377.0			235.0(1)	
11				2,680.0			
12	10.0		102.5			310.0(2)	
13	3.5						
14				360.0			
15	10.9	153,000					
16	0.77	208,000					
17			180.5			84.0	
18				1,280.0			
19			1,685.0			1,837.6	
20				11,580.0			12,000.0
21		- 8.3					
22		- 3.5					

(1) The two given values seem to be in discrepency since the computed average trip-rate of comm.veh. - 235,000/80,000 = 2.9, is much too low;

(2) The given number seems to be very high.

4. BALTIMORE - 1985

	A	B	C	D	E	F	G
a		2,161,000					
b		33.9					
c		2,220					
1	33.9	734,300			734,270		
2		3.5			3.5		
3			2,570.0			2,542.2	
4		26.5					
5		9.7			11.4		
6				24,900.0			
7	13.0	95,500					
8		650,000					
9	16.5	424,000					
10			537.0			(588.6)	
11				5,210.0			
12							
13							
14							
15	16.6	516,000					
16	0.46	338,000					
17			427.0			455.6	
18				4,150.0			
19			3,534.0			3,586.4	
20				34,260.0			41,000.0
21		- 1.5					
22		- 16.4					

6. BELFAST - 1966

	A	B	C	D	E	F	G
a		504,620					
b		12.8					
c		127					
1	12.8	64,300			64,248		
2		6.0					
3			386.0			361.4	
4		6.4					
5		4.2					
6				1,620.0			
7	16.0	10,300					
8		54,000					
9	33.2	128,000					
10			91.0			103.3	
11				382.0			
12							
13							
14							
15	12.4	59,000					
16	1.86	119,500					
17			89.3			97.1	
18				375.0			
19			566.3			561.8	
20				2,377.0			21607.5
21		+ 0.8					
22		- 8.9					

5. BATON ROUGE - 1965

	A	B	C	D	E	F	G
a	35.2	245,076					
b		35.2					
c		393					
1		86,200			86,116		
2		4.0					
3			345.0			410.0	
4		11.2					
5		6.0					
6				2,070.0			
7	13.2	11,400			9,101		
8		64,000					
9		54,000					
10			59.0			81.4	
11				354.0			
12							
13							
14							
15	16.8	67,700					
16	0.83	71,500					
17			69.6			71.8	
18				418.0			
19			473.6			563.2	
20				2,842.0			3,025.0
21		- 15.9					
22		- 6.1					

5. BATON ROUGE - 1985

	A	B	C	D	E	F	G
a		443,000					
b		39.8					
c		393					
1	39.8	176,000			176,470		
2		4.3					
3			756.0			841.7	
4		11.2					
5		6.9					
6				5,220.0			
7	13.0	22,900					
8		161,000					
9	13.0	98,500					
10			129.8			153.2	
11				895.0			
12							
13							
14							
15	17.0	151,000					
16	0.83	146,000					
17			148.5			210.8	
18				1,025.0			
19			1,034.3			1,205.7	
20				7,140.0			8,500.0
21		- 14.2					
22		- 16.0					

7. B I R M I N G H A M - 1964

	A	B	C	D	E	F	G
a		2,529,010					
b		15.4					
c		970					
1	15.4(1)	388,400			388,353		
2		3.2			3.1		
3			1,242.0			1,309.9	
4		17.5					
5		6.8			5.6(2)		
6				8,450.0			
7	15.2	59,000					
8		375,000					
9	31.5	391,000					
10			383.0			341.7	
11				2,605.0			
12							
13							
14							
15	13.4	218,000					
16	0.55	213,500					
17			215.8			273.3	
18				1,465.0			
19			1,840.8			1,924.9	
20				12,520.0			10,700.0
21		- 4.4	(1) Including Motorcycles;				
22		+ 17.0	(2) Trip Length affected by Motorcycles.				

7. B I R M I N G H A M - 1981

	A	B	C	D	E	F	G
a		2,670,900					
b		30.7					
c		970					
1	30.7(1)	820,000			820,000		
2		3.4			3.2		
3			2,790.0			2,654.7	
4		17.5					
5		8.4			5.9(2)		
6				23,400.0			
7	13.3	109,000			85,000		
8		720,000					
9	18.5	530,000					
10			625.0			559.9	
11				5,250.0			
12							
13							
14							
15	16.0	546,000					
16	0.54	442,000					
17			494.0			592.0	
18				4,150.0			
19			3,909.0			3,806.6	
20				32,800.0			22,600.0
21		+ 2.7	(1) Including Motorcycles;				
22		+ 45.2	(2) Trip Length affected by Motorcycles.				

8. BOMBAY - 1981

	A	B	C	D	E	F	G
a		8,058,000					
b		1.85					
c		850					
1	1.85	149,000			148,753		
2		4.3			4.6		
3			640.0			690.8	
4		16.4					
5		8.2			8.9		
6				5,250.0			
7	50.0	74,500			32,000		
8		520,000					
9	41.5	266,000					
10			393.0			140.5	
11				3,220.0			
12	48.0		307.0			293.9	
13	4.1						
14				1,260.0			
15	4.4	45,500					
16	0.57	59,000					
17			50.3			40.0	
18				412.0			
19			1,390.3			1,165.2	
20				10,142.0			10,364.0
21		+ 19.3					
22		- 2.1					

11. CHATTANOOGA - 1982

	A	B	C	D	E	F	G
a		344,528					
b		32.0					
c		490					
1	32.0	110,000			110,248		
2		5.0			4.0		
3			550.0			440.0	
4		12.5					
5		7.3			8.1		
6				4,020.0			
7	13.5	14,850			17,600		
8		92,000					
9	17.5	99,000					
10			95.5			88.0	
11				725.0			
12							
13							
14							
15	16.4	106,000					
16	0.73	80,300					
17			93.2			141.1	
18				680.0			
19			738.7			669.1	
20				5,425.0			5,437.0
21		+ 10.4					
22		- 0.2					

9. B R I S B A N E - 1960

	A	B	C	D	E	F	G
a		593,668					
b		20.0					
c		970					
1	20.0	119,000			118,827		
2		3.4			2.7		
3			428.0			334.8	
4		17.5					
5		6.8			7.5		
6				2,910.0			
7	14.2	16,900			37,334		
8		110,000					
9	27.5	117,500					
10			113.8			171.7	
11				774.0			
12							
13							
14							
15	14.8	80,200					
16	0.54	64,200					
17			72.2			28.1	
18				490.0			
19			614.0			544.6	
20				4,174.0			4,036.0(1)
21		+ 12.7	(1) Total Kilometrage computed by multiplying				
22		+ 3.4	number of trips x average trip length.				

9. B R I S B A N E - 1981

	A	B	C	D	E	F	G
a		1,020,800					
b		35.4					
c		970					
1	35.4	361,000			361,270		
2		3.6			3.2		
3			1,300.0			1,162.0	
4		17.5					
5		8.4			8.9		
6				10,920.0			
7	13.0	47,000					
8		355,000					
9	15.0	201,000					
10			278.0			353.7	
11				2,340.0			
12							
13							
14							
15	16.8	265,000					
16	0.54	199,000					
17			230.0			94.9	
18				1,930.0			
19			1,808.0			1,610.6	
20				15,190.0			14,860.0
21		+ 12.2					
22		+ 2.2					

12. C H I C A G O - 1980

	A	B	C	D	E	F	G
a		7,802,000					
b		36.2					
c		1,430					
1	36.2	2,830,000			2,828,000		
2		3.4			3.6		
3			9,620.0			10,194.0	
4		21.3					
5		9.1			8.8		
6				87,500.0			
7	13.0	368,000			211,000		
8		1,700,000					
9	15.0	1,440,000					
10			1,570.0			2,467.0	
11				14,300.0			
12							
13							
14							
15	16.7	1,870,000					
16	0.50	1,415,000					
17			1,642.5				
18				14,950.0			
19			12,832.5			12,661.0 (1)	
20				116,750.0			108,700.0(1)
21		+ 1.4	(1) Given data includes internal trips &				
22		+ 7.4	Kilometrage only.				

13. C O L U M B I A - 1985

	A	B	C	D	E	F	G
a		365,463					
b		41.3					
c		470					
1	41.3	151,000			150,780		
2		4.3			4.6		
3			650.0			697.7	
4		12.2					
5		7.2			7.0		
6				4,680.0			
7	13.0	19,600			19,000		
8		132,000					
9	13.0	83,500					
10			107.8			87.6	
11				775.0			
12							
13							
14							
15	17.0	129,000					
16	0.74	112,000					
17			121.0			164.8	
18				870.0			
19			878.8			950.1	
20				6,325.0			6,620.0
21		- 7.5					
22		- 4.5					

14. COPENHAGEN - 1967

	A	B	C	D	E	F	G
a		1,707,000					
b		20.1					
c		2,756					
1	20.1(1)	343,000			342,950		
2		3.2			4.2		
3			1,100.0			1,445.3	
4		29.6					
5		7.6			7.9		
6				8,350.0			
7	14.3	49,000			47,240		
8		370,000					
9	27.4	301,000					
10			335.5			543.7	
11				2,550.0			
12							
13							
14							
15	14.8	212,000					
16	0.45	154,000					
17			183.0			40.8	
18				1,390.0			
19			1,618.5			2,029.8	
20				12,290.0			16,038.0
21		- 20.2	(1) Passenger cars include part of Commer-				
22		- 23.4	cial vehicles.				

14. COPENHAGEN - 1985

	A	B	C	D	E	F	G
a		2,077,730					
b		44.2					
c		2,756					
1	44.2	915,000			915,350		
2		3.4			3.6		
3			3,110.0			3,272.2	
4		29.6					
5		9.9			9.5		
6				30,800.0			
7	12.5	114,000					
8		740,000					
9	13.0	405,000					
10			572.5			742.6	
11				5,670.0			
12							
13							
14							
15	17.2	634,000					
16	0.45	412,000					
17			523.0			164.1	
18				5,180.0			
19			4,205.5			4,178.9	
20				41,650.0			39,791.0
21		- 0.6					
22		- 4.7					

16. H E L S I N K I - 1966

	A	B	C	D	E	F	G
a		637,393					
b		12.8					
c		733					
1	12.8	81,500			81,488		
2		4.0			2.7		
3			326.0			219.6	
4		15.2					
5		6.6			6.9		
6				2,150.0			1,530.0
7	16.3	13,300			13,030		
8		80,000					
9	33.0	107,500					
10			93.8			139.2	
11				618.0			
12							
13							
14							
15	12.4	52,000					
16	0.60	49,000					
17			50.5			33.9	
18				333.0			
19			470.3			392.7	
20				3,101.0			1,899.0(1)
21		+ 19.8	(1) Internal Kilometrage of Passenger Cars only.				
22		+ 63.4					

16. H E L S I N K I - 2000

	A	B	C	D	E	F	G
a		1,100,000					
b		39.0					
c		733					
1	39.0	429,000			429,000		
2		3.5			3.5		
3			1,500.0			1,123.5	
4		15.2					
5		7.9			11.9(1)		
6				11,850.0			
7	13.0	55,700			38,900		
8		410,000					
9	13.0	195,000					
10			302.5			434.5	
11				2,390.0			
12							
13							
14							
15	16.8	303,000					
16	0.60	108,000					
17			255.0			178.4	
18				2,015.0			
19			2,057.5			1,736.4	
20				16,255.0			21,649.0
21		+ 18.5	(1) Average trip length seems to be very high.				
22		- 24.9					

17. K I N G S T O N - 1967

	A	B	C	D	E	F	G
a		344,890					
b		12.5					
c		107					
1	12.5	43,000			43,183		
2		6.0			5.2		
3			280.0			226.0	
4		5.8					
5		3.9			4.2		
6				1,090.0			
7	17.0	7,300			9,469		
8		32,000					
9	33.4	93,500					
10			62.8			69.1	
11				245.0			
12							
13							
14							
15	12.2	41,800					
16	2.0	86,000					
17			63.9			62.1	
18				249.0			
19			406.7			357.2	
20				1,584.0			1,482.0
21		+ 13.9					
22		+ 6.9					

17. K I N G S T O N - 1981

	A	B	C	D	E	F	G
a		372,500					
b		26.1					
c		107					
1	26.1	97,000			97,170		
2		5.4			5.6		
3			524.0			543.0	
4		5.8					
5		4.6			4.8		
6				2,405.0			
7	13.7	13,300			11,819		
8		80,000					
9	22.8	119,000					
10			99.5			90.9	
11				457.0			
12							
13							
14							
15	16.0	99,500					
16	2.0	194,000					
17			146.8			114.1	
18				675.0			
19			770.3			748.0	
20				3,537.0			3,503.0
21		+ 0.3					
22		+ 1.0					

18. K N O X V I L L E - 1982

	A	B	C	D	E	F	G
a		335,714					
b		36.6					
c		1,360					
1	36.6	123,000			122,740		
2		4.8			4.7		
3			590.0			577.0	
4		20.8					
5		9.0			10.5		
6				5,300.0			
7	13.0	16,000					
8		102,000					
9	14.6	86,000					
10			94.0			84.0	
11				846.0			
12							
13							
14							
15	16.8	115,000					
16	0.50	61,500					
17			88.3			164.8	
18				785.0			
19			772.3			825.8	
20				6,931.0			8,700.0
21		- 6.5					
22		- 20.3					

19. L O N D O N - 1961

	A	B	C	D	E	F	G
a		8,826,620					
b		14.1					
c		2,450					
1	14.1	1,250,000			1,249,453		
2		3.1			2.9		
3			3,880.0			3,648.7	
4		28.0					
5		7.6			8.2		
6				29,500.0			
7	15.5	194,000			190,754		
8		1,110,000					
9	32.2	1,250,000					
10			1,180.0			1,062.4	
11				8,970.0			
12							
13							
14							
15	12.9	653,000					
16	0.46	575,000					
17			614.0			557.3	
18				4,660.0			
19			5,674.0			5,268.4	
20				43,130.0			39,200.0
21		+ 7.7					
22		+ 10.0					

19. L O N D O N - 1981

	A	B	C	D	E	F	G
a		9,141,000					
b		27.0					
c		2.450					
1	27.0	2,465,000			2,465,000		
2		3.4			3.3		
3			8,400.0			8,160.0	
4		28.0					
5		9.8			9.0		
6				82,400.0			
7	13.5	333,000			329,000		
8		1,610,000					
9	22.0	1,850,000					
10			1,730.0			1,767.0	
11				16,950.0			
12							
13							
14							
15	16.0	1,620,000					
16	0.46	1,135,000					
17			1,377.5			1,220.0	
18				13,500.0			
19			11,507.5			11,147.0	
20				112,850.0			101,650.0
21		+ 3.2					
22		+ 11.0					

20. MELBOURNE - 1964

	A	B	C	D	E	F	G
a		1,951,000					
b		26.5					
c		1,500					
1	26.5	517,000			517,000		
2		3.2			2.7		
3			1,650.0			1,419.7	
4		21.8					
5		7.2			7.6		
6				11,880.0			11,600.0
7	13.7	70,800			91,500		
8		510,000					
9	22.5	371,000					
10			440.5			519.0	
11				3,170.0			3,000.0
12							
13							
14							
15	16.0	334,000					
16	0.50	103,000					
17			218.5			85.4	
18				1,573.0			
19			2,309.0			2,024.1	
20				16,623.0			14,600.0
21		+ 14.1					
22		+ 13.9					

20. MELBOURNE - 1985

	A	B	C	D	E	F	G
a		3,700,000					
b		35.0					
c		1,500					
1	35.0	1,291,400			1,291,400		
2		3.4			4.7		
3			4,400.0			6,116.0	
4		21.8					
5		9.1			9.9		
6				40,000.0			60,230.0
7	13.0	168,000			194,000		
8		1,000,000					
9	16.0	704,000					
10			852.0			1,206.0	
11				7,750.0			12,220.0
12							
13							
14							
15	16.6	874,000					
16	0.50	646,000					
17			760.0			187.6	
18				6,910.0			
19			6,012.0			7,509.6	
20				54,660.0			72,450.0
21		- 19.9					
22		- 24.6					

21. M O N R O E - 1965

	A	B	C	D	E	F	G
a		96,608					
b		32.8					
c		200					
1	32.8	31,700			31,678		
2		5.5					
3			175.0			183.2	
4		8.0					
5		4.8					
6				840.0			
7	13.4	4,250					
8							
9	17.4	30,500					
10			30.5			40.9	
11				146.0			
12						(1.5)	
13							
14							
15	16.5	33,900					
16	1.36	43,100					
17			38.5			31.4	
18				185.0			
19			244.0			255.5	
20				1,171.0			1,151.2
21		- 4.5					
22		+ 1.7					

21. M O N R O E - 1985

	A	B	C	D	E	F	G
a		162,500					
b		49.7					
c		200					
1	49.7	80,700			80,760		
2		5.5					
3			444.0			406.3	
4		8.0					
5		5.6					
6				2,485.0			
7	13.0	10,500					
8		56,000					
9	13.0	57,600					
10			56.8			71.3	
11				318.0			
12							
13							
14							
15	17.1	85,500					
16	1.36	110,000					
17			97.8			97.0	
18				546.0			
19			598.6			574.6	
20				3,349.0			2,460.0
21		+ 4.2					
22		+ 36.1					

22. ORLANDO - 1985

	A	B	C	D	E	F	G
a		834,000					
b		42.1					
c		1,400					
1	42.1	351,000			351,000		
2		3.6					
3			1,262.0			1,410.8	
4		21.1					
5		9.0					
6				11,350.0			
7	13.0	45,600					
8		345,000					
9	13.0	164,000					
10			254.5			171.4	
11				2,290.0			
12						(9.6)	
13							
14							
15	17.0	258,000					
16	0.50	175,500					
17			216.8			213.8	
18				1,950.0			
19			1,733.3			1,796.0	
20				15,590.0			18,660.0
21		- 3.5					
22		- 16.5					

25. PULASKI - 1990

	A	B	C	D	E	F	G
a		412,103					
b		42.5					
c		720					
1	42.5	175,000			175,178		
2		4.2					
3			735.0				
4		15.1					
5		7.8					
6				5,750.0			
7	13.0	22,800					
8		160,000					
9	13.0	95,500					
10			127.8				
11				955.0			
12							
13							
14							
15	17.0	147,000					
16	0.60	105,000					
17			126.0				
18				982.0			
19			988.8			1,385.0	
20				7,677.0			9,970.0
21		- 28.6					
22		- 23.0					

23. PITTSBURGH - 1958

	A	B	C	D	E	F	G
a		1,469,375					
b		26.9					
c		1,085					
1	26.9	395,300			395,321		
2		3.2			3.2		
3			1,265.0			1,256.5	
4		18.5					
5		7.0			7.5		
6				8,850.0			
7	13.8	54,500			41,903		
8		410,000					
9	22.1	280,000					
10			345.0			229.4	
11				2,415.0			
12							
13							
14							
15	16.0	258,000					
16	0.53	209,500					
17			233.8			307.4	
18				1,633.0			
19			1,843.8			1,793.3	
20				12,898.0			13,800.0
21		+ 2.8					
22		- 6.5					

23. PITTSBURGH - 1980

	A	B	C	D	E	F	G
a		1,902,185					
b		34.4					
c		1,085					
1	34.4	654,000			654,263		
2		3.5			3.4		
3			2,290.0			2,251.3	
4		18.5					
5		8.6			7.5		
6				19,700.0			
7	13.0	85,000			61,700		
8		600,000					
9	16.3	373,000					
10			486.5			349.5	
11				4,190.0			
12							
13							
14							
15	16.7	464,000					
16	0.53	346,000					
17			405.0			433.0	
18				3,480.0			
19			3,181.5			3,033.8	
20				27,370.0			24,200.0
21		+ 4.9					
22		+ 13.5					

26. RAPID CITY - 1985

	A	B	C	D	E	F	G
a		130,110					
b		48.2					
c		276					
1	48.2	62,500			62,550		
2		5.0					
3			312.0			277.7	
4		9.4					
5		6.2					
6				1,934.0			
7	13.0	8,100					
8		38,000					
9	13.0	40,500					
10			39.3			33.1	
11				243.0			
12							
13							
14							
15	17.0	59,700					
16	1.05	65,500					
17			62.6			30.5	
18				388.0			
19			413.9			341.3	
20				2,565.0			1,852.0
21		+ 21.3					
22		+ 38.5					

27. RICHMOND - 1980

	A	B	C	D	E	F	G
a		550,660					
b		37.1					
c		346					
1	37.1	204,000			204,434		
2		4.0					
3			817.0			958.0	
4		10.5					
5		6.6					
6				5,400.0			
7	13.0	26,500					
8		195,000					
9	14.0	114,000					
10			155.0			137.5	
11				1,025.0			
12							
13							
14							
15	16.8	140,000					
16	0.88	179,000					
17			159.5			360.2	
18				1,050.0			
19			1,131.5			1,455.7	
20				7,475.0			16.320.0
21		- 22.2					
22		- 54.1					

28. R O T T E R D A M - 1966

	A	B	C	D	E	F	G
a		1,060,005					
b		13.1					
c		645					
1	13.1	139,000			139,000		
2		3.4			3.3		
3			472.5			437.7	
4		14.3					
5		6.5			8.1		
6				3,070.0			
7	16.5	23,000			(18,200)		
8		162,000					
9	32.8	155,000					
10			158.5			106.1	
11				1,030.0			
12							
13							
14							
15	12.5	79,000					
16	0.64	89,000					
17			84.0			183.5	
18				546.0			
19			715.0			727.3	
20				4,646.0			5,820.0(1)
21		- 1.7	(1) Given Kilometrage includes External Kilometrage.				

28. R O T T E R D A M - 1990

	A	B	C	D	E	F	G
a		1,573,564					
b		26.8					
c		645					
1	26.8	422,000			422,000		
2		3.5			3.3		
3			1,480.0			1,393.1	
4		14.3					
5		7.7			9.1		
6				11,400.0			
7	13.5	57,000					
8		420,000					
9	22.0	326,000					
10			373.0			130.5	
11				2,870.0			
12							
13							
14							
15	16.0	296,000					
16	0.64	270,000					
17			284.0			606.7	
18				2,190.0			
19			2,137.0			2,130.3	
20				16,460.0			19,210.0(1)
21		+ 0.3	(1) Given Kilometrage includes External Kilometrage.				

29. SIOUX FALLS - 1985

	A	B	C	D	E	F	G
a		127,789					
b		48.5					
c		147					
1	48.5	62,000			61,900		
2		6.4					
3			397.0			374.3	
4		6.8					
5		5.0					
6				1,985.0			
7	13.0	8,060					
8		38,000					
9	13.0	51,600					
10			44.8			41.0	
11				224.0			
12							
13							
14							
15	17.0	22,100					
16	1.7	105,000					
17			63.5			54.7	
18				318.0			
19			505.3			470.0	
20				2,527.0			2,520.0
21		+ 7.5					
22		+ 0.3					

31. TUCSON - 1980

	A	B	C	D	E	F	G
a		680,000					
b		52.0					
c		1,580					
1	52.0	354,000			354,000		
2		3.6					
3			1,275.0			1,378.9	
4		22.4					
5		9.2					
6				11,720.0			
7	13.0	46,000					
8		350,000					
9	13.0	166,000					
10			258.0			250.0	
11				2,370.0			
12						(7.5)	
13							
14							
15	17.0	261,000					
16	0.50	177,000					
17			219.0			61.0	
18				2,015.0			
19			1,752.0			1,689.9	
20				16,105.0			13,480.0
21		+ 3.7					
22		+ 19.5					

30. T E L - A V I V - 1965

	A	B	C	D	E	F	G
a		817,000					
b		4.9					
c		190					
1	4.9	40,000			39,643		
2		7.5			7.8		
3			300.0			309.5	
4		7.8					
5		4.7			4.1		
6				1,410.0			
7	29.0	11,600			13,070		
8		66,000					
9	39.4	118,000					
10			92.0			118.8	
11				432.0			
12							
13							
14							
15	7.5	29,400					
16	1.4	56,000					
17			42.7			30.4	
18				201.0			
19			434.7			458.7	
20				2,043.0			1,873.3
21		- 5.2					
22		+ 9.1					

30. T E L - A V I V - 1985

	A	B	C	D	E	F	G
a		1,225,000					
b		16.1					
c		190					
1	16.1	198,000			197,570		
2		4.0			6.8		
3			792.0			1,350.0	
4		7.8					
5		5.4			5.4		
6				4,280.0			
7	15.0	29,700			35,563		
8		220,000					
9	30.5	242,000					
10			231.0			337.5	
11				1,250.0			
12							
13							
14							
15	13.6	139,000					
16	1.4	277,000					
17			208.0			159.9	
18				1,125.0			
19			1,231.0			1,847.4	
20				6,655.0			9,891.3
21		- 33.4					
22		- 32.7					

32. W E S T M I D L A N D S - 1964

	A	B	C	D	E	F	G
a		2,529,010					
b		15.4					
c		972					
1	15.4	388,000			388,353		
2		3.2					
3			1,240.0			1,220.0	
4		17.6					
5		6.9					
6				8,550.0			
7	15.2	59,000			53,956		
8		435,000					
9		388,000					
10			411.5			(234.5)(1)	
11				2,840.0			
12							
13							
14							
15	13.4	222,000					
16	0.54	210,000					
17			216.0			280.3	
18				1,490.0			
19			1,867.5			1,734.8	
20				12,880.0			10,100.0
21		+ 7.7					
22		+ 27.5					

(1) Inter-zonal trips only.

32. W E S T M I D L A N D S - 1981

	A	B	C	D	E	F	G
a		2,670,900					
b		30.8					
c		972					
1	30.8	822,000			822,000		
2		3.4					
3			2,800.0				
4		17.6					
5		8.4					
6				23,500.0			
7	13.4	110,000					
8		730,000					
9	19.0	533,000					
10			631.5				
11				5,300.0			
12							
13							
14							
15	16.4	562,500					
16	0.54	441,500					
17			500.2				
18				4,200.0			
19			3,931.7			3,284.7 (1)	
20				33,000.0			22,500.0
21		+ 19.7					
22		+ 46.7					

(1) Discrepancies between 'Trips' and 'Journeys'.

33. W I N S T O N S A L E M - 1985

	A	B	C	D	E	F	G
a		256,169					
b		49.8					
c		400					
1	49.8	127,500			127,898		
2		4.6					
3			586.0			502.6	
4		11.3					
5		6.8					
6				3,990.0			
7	13.0	16,600					
8		106,000					
9	13.0	76,000					
10			91.0			59.4	
11				619.0			
12							
13							
14							
15	17.0	115,000					
16	0.83	106,000					
17			110.5			231.0	
18				750.0			
19			787.5			793.0	
20				5,359.0			5,280.0
21		- 0.7					
22		+ 1.5					

34. Z U R I C H - 1960

	A	B	C	D	E	F	G
a		700,000					
b		7.8					
c		402					
1	7.8	54,500			54,300		
2		6.5					
3			354.0				
4		11.3					
5		5.9					
6				2,090.0			
7	21.5	11,700					
8		65,000					
9	37.0	131,000					
10			98.0				
11				578.0			
12							
13							
14							
15	9.7	43,800					
16	0.82	44,700					
17			44.3				
18				261.0			
19			496.3			529.2	
20				2,929.0			3,267.0
21		- 6.2					
22		- 10.3					

APPENDIX 6 Table 6.1

Potential Field of Vehicles - 1965

P= PRIVATE VEHICLES

V= POTENTIAL

ZONE	P	V		ZONE	P	V		ZONE	P	V		ZONE	P	V
1	0.	12664.41		21	971.00	20066.69		41	251.00	10279.63		61	926.00	14573.02
2	0.	13400.50		22	0.	17207.70		42	358.00	10225.64		62	1332.00	14705.34
3	199.00	11672.82		23	0.	18038.49		43	0.	8085.77		63	546.00	13450.19
4	1246.00	14640.13		24	367.00	18187.31		44	0.	9665.60		64	186.00	10399.19
5	20.00	12841.62		25	189.00	14463.18		45	7.00	7739.43		65	386.00	8605.32
6	0.	12813.98		26	234.00	16450.11		46	0.	8321.15		66	84.00	8836.54
7	813.00	10729.41		27	24.00	15803.39		47	1410.00	9332.12		67	0.	6783.79
8	672.00	9233.38		28	544.00	16007.12		48	510.00	6782.21		68	382.00	9285.43
9	896.00	19726.43		29	460.00	15785.61		49	1569.00	9965.14		69	8.00	8704.16
10	2279.00	21801.14		30	346.00	12041.00		50	881.00	9954.23		70	2322.00	7077.94
11	885.00	18767.25		31	821.00	13611.27		51	481.00	7235.28		71	577.00	6090.72
12	1500.00	22162.05		32	328.00	14757.68		52	129.00	8179.24		72	129.00	3692.71
13	2224.00	24802.44		33	928.00	14352.33		53	152.00	8387.88		73	0.	0.
14	1207.00	21305.18		34	56.00	12749.13		54	1281.00	13200.41		74	0.	0.
15	0.	18962.16		35	209.00	12648.37		55	988.00	15060.03		75	0.	0.
16	1206.00	25713.34		36	81.00	11579.57		56	1360.00	17471.28		76	0.	0.
17	2913.00	2 252.08		37	77.00	10270.24		57	2573.00	19455.90		77	0.	0.
18	147.00	20519.23		38	88.00	10688.67		58	1264.00	17264.62		78	0.	0.
19	134.00	18900.20		39	0.	10807.01		59	1238.00	18095.47		79	0.	0.
20	802.00	18844.73		40	309.00	9608.45		60	1785.00	19037.34				

APPENDIX 6 Table 6.2

Potential Field of Vehicles - 1985

P= PRIVATE VEHICLES

V= POTENTIAL

ZONE	P	V		ZONE	P	V		ZONE	P	V		ZONE	P	V
1	288.00	65348.55		21	3933.00	88085.29		41	2545.00	68713.54		61	6691.00	78969.38
2	6205.00	72363.77		22	265.00	82703.09		42	1113.00	58693.64		62	6534.00	80104.18
3	3175.00	66208.05		23	322.00	85318.37		43	1345.00	48482.65		63	3667.00	73959.57
4	3331.00	75235.87		24	1802.00	89220.38		44	1236.00	55677.91		64	1399.00	59303.69
5	203.00	69395.35		25	1485.00	73261.38		45	423.00	45583.00		65	5219.00	52628.58
6	0.	69577.10		26	1072.00	79497.74		46	2.00	47573.60		66	1032.00	52591.08
7	8386.00	63967.08		27	129.00	79042.22		47	10460.00	62439.51		67	2637.00	42087.04
8	11935.00	58452.28		28	3360.00	83202.36		48	7887.00	47241.99		68	1901.00	53024.60
9	3025.00	80890.07		29	3798.00	85635.30		49	10337.00	66470.67		69	1351.00	47392.63
10	5342.00	89614.75		30	3872.00	70204.11		50	7479.00	66895.75		70	8816.00	43248.02
11	5122.00	84831.86		31	2433.00	73466.27		51	6848.00	49295.20		71	9664.00	37318.19
12	3543.00	84521.49		32	1580.00	77533.60		52	4420.00	53950.71		72	2394.00	22715.62
13	5536.00	93967.29		33	3226.00	77773.18		53	1856.00	54023.11		73	0.	0.
14	4465.00	90260.70		34	245.00	71997.09		54	5712.00	72912.21		74	0.	0.
15	404.00	87023.99		35	5948.00	74267.89		55	7395.00	79871.86		75	0.	0.
16	2678.00	94729.00		36	2911.00	73208.64		56	5452.00	87627.30		76	0.	0.
17	6262.00	93158.40		37	1764.00	64698.88		57	6276.00	89464.10		77	0.	0.
18	241.00	87353.65		38	1833.00	71726.73		58	5820.00	82299.90		78	0.	0.
19	95.00	86473.20		39	3526.00	69805.50		59	4657.00	89674.85		79	0.	0.
20	3252.00	81930.66		40	2240.00	62171.24		60	7204.00	89825.46				

APPENDIX 6 Table 6.3

Potential Field of Employment - 1965

P= TOTAL EMPLOYMENT

V= POTENTIAL

ZONE	P	V		ZONE	P	V		ZONE	P	V		ZONE	P	V
1	228.00	64519.60		21	5928.00	172052.48		41	700.00	75804.96		61	3754.00	69933.25
2	61.00	64252.43		22	10402.00	150606.18		42	646.00	49762.00		62	4201.00	72611.49
3	817.00	55516.74		23	3111.00	122377.49		43	0.	42166.48		63	3561.00	67372.60
4	1146.00	63691.89		24	395.00	105495.76		44	0.	49792.84		64	348.00	54567.07
5	473.00	60479.04		25	3806.00	161227.11		45	0.	41361.10		65	1398.00	47262.99
6	40.00	63353.94		26	29624.00	204333.26		46	701.00	44004.31		66	2740.00	48764.77
7	2651.00	54415.12		27	6292.00	195455.96		47	4016.00	57153.98		67	646.00	40364.16
8	5140.00	49821.37		28	1822.00	118358.83		48	2036.00	41368.19		68	6544.00	52707.32
9	5322.00	96796.26		29	1017.00	89883.61		49	1945.00	60595.69		69	2025.00	48673.65
10	3232.00	96969.45		30	13227.00	132330.50		50	4376.00	61825.62		70	12131.00	41735.38
11	1166.00	84905.12		31	21064.00	151757.29		51	1178.00	43717.15		71	2627.00	34503.50
12	6622.00	128057.13		32	5807.00	139362.22		52	2629.00	54699.42		72	553.00	21216.53
13	5695.00	118363.50		33	4756.00	103259.58		53	3604.00	55512.05		73	0.	0.
14	2938.00	108355.25		34	529.00	89744.48		54	1471.00	66949.22		74	0.	0.
15	60.00	97305.51		35	2118.00	76446.13		55	2301.00	69866.30		75	0.	0.
16	4483.00	151822.60		36	722.00	95426.56		56	1534.00	77089.02		76	0.	0.
17	7766.00	142303.39		37	5075.00	101785.51		57	6952.00	90254.53		77	0.	0.
18	5479.00	133290.88		38	1136.00	97162.55		58	9935.00	84847.04		78	0.	0.
19	1993.00	108972.82		39	2015.00	92968.41		59	343.00	89968.40		79	0.	0.
20	15178.00	165397.83		40	1850.00	72928.18		60	3752.00	90290.32				

APPENDIX 6 Table 6.4

Potential Field of Employment - 1985

P= TOTAL EMPLOYMENT

V= POTENTIAL

ZONE	P	V	ZONE	P	V	ZONE	P	V	ZONE	P	V
1	1525.00	105539.07	21	5935.00	242151.05	41	1747.00	124324.05	61	6100.00	123055.60
2	1811.00	108447.50	22	17080.00	232239.79	42	1019.00	89533.42	62	7604.00	129259.36
3	1621.00	99212.21	23	4875.00	198057.35	43	1246.00	76980.00	63	8722.00	121119.87
4	2340.00	111842.75	24	1175.00	175299.35	44	1473.00	87761.60	64	1098.00	97867.46
5	3132.00	108220.78	25	24286.00	253288.41	45	831.00	74307.70	65	4529.00	86126.46
6	1324.00	112501.52	26	29306.00	284057.05	46	874.00	77475.08	66	4773.00	87995.68
7	5125.00	99319.98	27	8688.00	281420.00	47	7285.00	100926.92	67	2396.00	73288.29
8	17392.00	94410.20	28	2300.00	189151.85	48	13360.00	80245.11	68	13237.00	95940.78
9	4677.00	138933.71	29	1672.00	153493.39	49	8814.00	112010.08	69	9767.00	80992.13
10	3325.00	144645.90	30	10785.00	188703.72	50	7477.00	117763.97	70	13899.00	79463.51
11	2501.00	134511.33	31	23412.00	221117.60	51	4867.00	83669.36	71	6883.00	61593.03
12	5846.00	176699.30	32	13571.00	216380.78	52	20656.00	105344.06	72	4120.00	38814.60
13	5928.00	168723.43	33	4162.00	170694.55	53	4894.00	109790.40	73	0.	0.
14	5408.00	169387.78	34	5456.00	160634.23	54	4506.00	119608.48	74	0.	0.
15	790.00	159759.43	35	8630.00	136354.02	55	4846.00	122820.58	75	0.	0.
16	5506.00	208096.99	36	1552.00	155349.97	56	3281.00	132745.67	76	0.	0.
17	7683.00	206153.12	37	4768.00	147200.13	57	9005.00	147304.84	77	0.	0.
18	13270.00	207844.44	38	2180.00	149169.38	58	12672.00	138622.84	78	0.	0.
19	4318.00	180483.91	39	4255.00	147408.84	59	2886.00	153629.59	79	0.	0.
20	14761.00	228096.88	40	2737.00	116776.24	60	6350.00	151419.12			

APPENDIX 6 Table 6.5

Potential Field of Population - 1965

P= POPULATION

V= POTENTIAL

ZONE	P	V	ZONE	P	V	ZONE	P	V	ZONE	P	V
1	14.00	177559.72	21	19054.00	330451.65	41	4559.00	226410.26	61	18994.00	238719.78
2	13.00	183088.70	22	2641.00	294016.22	42	1322.00	140643.34	62	22614.00	241635.82
3	1652.00	159352.12	23	1822.00	284684.25	43	13.00	117820.35	63	14092.00	218579.36
4	8761.00	190414.48	24	6300.00	287049.86	44	24.00	137708.99	64	4400.00	174283.85
5	1859.00	176911.18	25	15446.00	293849.05	45	23.00	114081.68	65	9125.00	149009.22
6	0.	184580.27	26	6795.00	312907.05	46	23.00	121904.44	66	316.00	153125.96
7	8784.00	156603.21	27	2023.00	306805.65	47	33984.00	193699.28	67	12170.00	126755.01
8	8698.00	141937.91	28	11327.00	288095.45	48	11816.00	133775.31	68	5366.00	153214.75
9	13204.00	264432.29	29	8175.00	265133.72	49	26270.00	194821.18	69	2715.00	143143.77
10	23264.00	281971.21	30	15256.00	265209.40	50	17160.00	192781.86	70	32455.00	125382.94
11	8429.00	249030.19	31	22633.00	278975.05	51	11544.00	140305.71	71	24114.00	109593.93
12	13505.00	298210.33	32	11119.00	287666.76	52	7426.00	157850.04	72	11866.00	67587.41
13	20383.00	314771.66	33	25656.00	278242.76	53	5150.00	159789.60	73	0.	0.
14	8782.00	283260.36	34	1491.00	249500.81	54	10197.00	214135.46	74	0.	0.
15	80.00	264904.14	35	11082.00	226332.84	55	20394.00	240857.44	75	0.	0.
16	12544.00	344381.34	36	7569.00	241951.52	56	20988.00	272474.18	76	0.	0.
17	22739.00	327495.98	37	15111.00	245644.54	57	26334.00	283357.66	77	0.	0.
18	2645.00	297187.20	38	8980.00	255506.05	58	21087.00	251741.24	78	0.	0.
19	1060.00	279383.63	39	3573.00	231198.53	59	10607.00	278629.14	79	0.	0.
20	19923.00	315512.81	40	15794.00	217250.64	60	25843.00	283310.92			

APPENDIX 6 Table 6.6

Potential Field of Population - 1985

P= POPULATION

V= POTENTIAL

ZONE	P	V		ZONE	P	V		ZONE	P	V		ZONE	P	V
1	1065.00	279897.33		21	16402.00	400727.88		41	12835.00	338610.49		61	38813.00	358256.22
2	12936.00	306422.73		22	1928.00	381751.96		42	3694.00	249680.58		62	32451.00	364045.65
3	11735.00	279859.96		23	1848.00	386476.44		43	4971.00	207793.58		63	19697.00	335157.41
4	12206.00	317189.68		24	8250.00	404159.52		44	4567.00	237560.77		64	6000.00	266762.10
5	970.00	296143.28		25	10796.00	355824.03		45	1562.00	196215.03		65	21971.00	236109.68
6	0.	300511.97		26	5159.00	378424.85		46	10.00	204914.53		66	3198.00	238004.57
7	33965.00	275767.00		27	848.00	380020.47		47	49070.00	295394.73		67	15019.00	193699.66
8	47659.00	254163.15		28	15053.00	390322.19		48	36236.00	219650.06		68	7910.00	237293.86
9	13552.00	349163.33		29	14039.00	389595.79		49	44688.00	308682.57		69	5659.00	209249.76
10	21954.00	382401.38		30	21449.00	348298.46		50	82384.00	310096.18		70	35683.00	193654.98
11	19532.00	362530.92		31	17695.00	359255.65		51	29424.00	228132.22		71	45889.00	168617.34
12	13449.00	368463.96		32	11494.00	375540.87		52	75194.00	252051.45		72	18102.00	104893.25
13	20109.00	400026.20		33	23451.00	377352.28		53	8134.00	254037.13		73	0.	0.
14	15174.00	388182.40		34	1787.00	348831.63		54	82506.00	329691.74		74	0.	0.
15	1728.00	380170.11		35	29996.00	344668.78		55	34059.00	360237.12		75	0.	0.
16	11062.00	413532.11		36	13044.00	350043.67		56	24195.00	394746.55		76	0.	0.
17	22846.00	406790.56		37	12827.00	326312.81		57	25144.00	397114.15		77	0.	0.
18	1295.00	387042.68		38	13331.00	364641.17		58	24479.00	361673.75		78	0.	0.
19	444.00	387813.30		39	17777.00	339862.11		59	18479.00	405351.07		79	0.	0.
20	17222.00	377761.52		40	16284.00	309575.62		60	38616.00	405588.59				

Appendix 7

Table 7.1

Potential Fields in Percent, Tel-Aviv

Base and Target Years

Zone	Pass. Cars		Employment		Population		Zone	Pass. Cars		Employment		Population	
	65	85	65	85	65	85		65	85	65	85	65	85
1	1.3	1.3	1.0	1.1	1.1	1.2	37	1.0	1.3	1.6	1.5	1.5	1.4
2	1.4	1.4	1.0	1.1	1.1	1.3	38	1.1	1.4	1.6	1.5	1.6	1.6
3	1.2	1.3	0.9	1.0	1.0	1.2	39	1.1	1.4	1.5	1.5	1.4	1.5
4	1.5	1.5	1.0	1.1	1.2	1.4	40	1.0	1.2	1.2	1.2	1.4	1.3
5	1.3	1.4	1.0	1.1	1.1	1.3	41	1.0	1.3	1.2	1.2	1.4	1.5
6	1.3	1.4	1.0	1.1	1.2	1.3	42	1.0	1.2	0.8	0.9	0.9	1.1
7	1.1	1.2	0.9	1.0	1.0	1.2	43	0.8	1.0	0.7	0.8	0.7	0.9
8	0.9	1.1	0.8	0.9	0.9	1.1	44	1.0	1.1	0.8	0.9	0.9	1.0
9	2.0	1.6	1.6	1.4	1.6	1.5	45	0.8	0.9	0.7	0.7	0.7	0.8
10	2.2	1.8	1.6	1.4	1.8	1.7	46	0.8	0.9	0.7	0.8	0.8	0.9
11	1.9	1.7	1.4	1.3	1.6	1.6	47	0.9	1.2	0.9	1.0	1.2	1.3
12	2.3	1.7	2.1	1.8	1.9	1.6	48	0.7	0.9	0.7	0.8	0.8	1.0
13	2.5	1.8	1.9	1.7	2.0	1.7	49	1.0	1.3	1.0	1.1	1.2	1.3
14	2.2	1.8	1.7	1.7	1.8	1.7	50	1.0	1.3	1.0	1.2	1.2	1.3
15	1.9	1.7	1.6	1.6	1.6	1.6	51	0.7	1.0	0.7	0.8	0.9	1.0
16	2.6	1.9	2.4	2.1	2.1	1.8	52	0.8	1.1	0.9	1.1	1.0	1.1
17	2.5	1.8	2.3	2.1	2.0	1.8	53	0.9	1.1	0.9	1.1	1.0	1.1
18	2.1	1.7	2.1	2.1	1.8	1.7	54	1.3	1.4	1.1	1.2	1.3	1.4
19	1.9	1.7	1.8	1.8	1.7	1.7	55	1.5	1.6	1.1	1.2	1.5	1.6
20	1.9	1.6	2.7	2.3	2.0	1.6	56	1.8	1.7	1.2	1.3	1.7	1.7
21	2.0	1.7	2.8	2.4	2.1	1.7	57	2.0	1.8	1.5	1.5	1.8	1.7
22	1.7	1.6	2.4	2.3	1.8	1.7	58	1.8	1.6	1.4	1.4	1.6	1.6
23	1.8	1.7	2.0	2.0	1.8	1.7	59	1.8	1.8	1.4	1.5	1.7	1.8
24	1.9	1.7	1.7	1.7	1.8	1.7	60	1.9	1.8	1.5	1.5	1.8	1.8
25	1.5	1.4	2.6	2.5	1.8	1.5	61	1.5	1.6	1.1	1.2	1.5	1.6
26	1.7	1.6	3.3	2.8	1.9	1.6	62	1.5	1.6	1.2	1.3	1.4	1.6
27	1.6	1.6	3.1	2.8	1.9	1.6	63	1.4	1.5	1.1	1.2	1.4	1.5
28	1.6	1.6	1.9	1.9	1.8	1.7	64	1.1	1.2	0.9	1.0	1.1	1.2
29	1.6	1.7	1.4	1.5	1.6	1.7	65	0.9	1.0	0.8	0.9	0.9	1.0
30	1.2	1.4	2.1	1.9	1.6	1.5	66	0.9	1.0	0.8	0.9	0.9	1.0
31	1.4	1.4	2.4	2.2	1.7	1.6	67	0.7	0.8	0.7	0.7	0.8	0.8
32	1.5	1.5	2.2	2.2	1.8	1.6	68	0.9	1.0	0.9	1.0	0.9	1.0
33	1.5	1.5	1.7	1.7	1.7	1.6	69	0.9	0.9	0.8	0.8	0.9	0.8
34	1.3	1.4	1.4	1.6	1.6	1.5	70	0.7	0.9	0.7	0.8	0.8	0.8
35	1.3	1.5	1.2	1.4	1.4	1.5	71	0.6	0.7	0.6	0.6	0.7	0.7
36	1.2	1.4	1.5	1.5	1.5	1.5	72	0.4	0.4	0.3	0.4	0.4	0.5

Het synthetiseren van een vervoersstudie door middel van de "IN"-methode.

(Dutch summary)

A. Synopsis van de dissertatie

Het doelmatig en veilig bewegen van mensen en goederen binnen een stedelijk gebied, wordt van wezenlijk belang geacht voor het verzekeren van het dynamische leven en de voorspoedige ontwikkeling van een gebied en zijn bevolking;

De vervoersstudie wordt algemeen beschouwd als een hoogst belangrijk instrument om bovengenoemde doelen te bereiken en in sommige landen is zo'n studie een voorwaarde voor de goedkeuring van overheidssteun voor de ontwikkeling van autosnelwegen in stedelijke gebieden met meer dan een bepaald aantal inwoners;

De enorme ontwikkeling van de vervoersstudie-technieken gedurende de laatste 10 jaren riep verscheidene kritieke problemen op, zoals de kolossale hoeveelheden tijd, moeite en geld welke aan het uitvoeren van zulke studies werden besteed. Aldus is men in de laatste tijd tot de conclusie gekomen dat er een dringende behoefte bestaat aan een nieuwe benaderingswijze, in het bijzonder voor het vereenvoudigen van de methoden voor het verzamelen en verwerken van de data;

Het doel van deze dissertatie is daarom om voor een snelle taxatie van de huidige of geprojecteerde verkeersbehoeften, alsook voor de evaluatie van alternatieven voor wegennetten welke voor de toekomst zijn gepland, zodanige methoden te analyseren en nieuw te ontwikkelen waardoor verkeerspatronen van voertuigen in een stedelijk gebied gemakkelijk en snel kunnen worden gesynthetiseerd;

De vijf voornaamste componenten van het betoog en de methode welke de grondslag vormen van deze dissertatie, kunnen aldus als

als volgt worden samengevat:

Stelling: Alle bekende methoden voor de vervoersanalyse van bestaande patronen of voor het voorspellen van vervoersbehoeften voor een prognosejaar, zijn gebaseerd op de gevestigde wetenschap dat vervoerspatronen dagelijks weerkeren en dat zij kunnen worden verklaard en gesynthetiseerd door de wisselwerking van meetbare parameters, welke karakteristiek zijn voor het stedelijk gebied en zijn bevolking;

Hypothese: Verkeerspatronen van voertuigen in een stedelijk gebied kunnen analytisch worden gesynthetiseerd door een beperkt aantal van slechts drie basis-parameters aan te wenden, nl. bevolking, motorisering en oppervlakte, met als resultaat uitgebreide verkeersdata van voldoende nauwkeurigheid voor het bij eerste benadering evalueren van huidige alsook geprojecteerde vervoerspatronen;

"IN"-model: Voertuigen kunnen worden beschouwd als een nieuwe en aparte populatie in een stedelijk gebied, met eigen karakter en inherent gedrag.
Indien wordt bewezen dat deze hypothese juist is, dan zou een methode volgens een duidelijk kortere weg kunnen worden ontwikkeld. Hierdoor zou de ingewikkelde analyse van talrijke individuele elementen van ritten in een stedelijk gebied kunnen worden omzeild. Alleen het gedrag van de gehele groep voertuigen als een nieuwe populatie in het gebied zou dan in beschouwing kunnen worden genomen;

Doel van de thesis: Het toetsen van de hypothese en het model, en het formuleren van een eenvoudige methode met de bedoeling planologen en stedebouwers een analytisch werktuig (tool) voor praktische toepassingen te verschaffen;

Methodologie: Afleiden van empirische verbanden door vergelijkende analyse van de beschikbare data, gepubliceerd in rapporten van vervoersstudies, en integreren van deze verbanden

in een analytische formulering.

Geloofd en gehoopt wordt dat deze dissertatie geslaagd mag heten ten aanzien van zowel het bewijzen van de hypothesen, alsook het ontwikkelen van de zo dringend noodzakelijke nieuwe methoden.

B. Samenvatting van de hoofdstukken

Inleiding: De vervoersstudie

De Inleiding opent met een algemene beschrijving van de doelstellingen van een normale integrale vervoersstudie en van de methoden welke hierbij worden toegepast. Ook worden enige tekortkomingen van zulke methoden toegelicht. Tenslotte volgt een beknopte weergave van doel en draagwijdte van de voor deze dissertatie uitgevoerde research.

Hoofdstuk 1: Het "IN"-model

Het hoofdstuk begint met de basishypothese, namelijk dat de voertuigen in een stedelijk gebied kunnen worden beschouwd als een nieuwe en aparte populatie in het gebied, met eigen karakteristieke en inherente gedragspatronen te baseren op slechts drie parameters, t.w. bevolking, motorisering en oppervlakte.

Vervolgens wordt de mathematische formulering voor het "IN"-model ontwikkeld, waarbij wordt aangetoond dat de "dynamische lengte" van rijstroken in een stedelijk gebied kunnen worden uitgedrukt in het INstant aantal voertuigen op het wegennet tijdens het spitsuur, en hun ruimtelijke gemiddelde snelheid.

Ook wordt aangetoond dat dit gemiddelde INstant aantal voertuigen op het netwerk tijdens het spitsuur gelijk is aan de verhouding tussen de kilometrage en de snelheid gedurende dat spitsuur, en daarom ook gelijk is aan de totale tijdsduur, welke door de voertuigen gedurende die tijd op het netwerk wordt doorgebracht.

Bovendien wordt eveneens aangetoond dat het INstant aantal voertuigen kan worden benaderd door middel van het totaal aantal

voertuigen dat in het gebied is geregistreerd. Het resultaat is een zeer laag percentage van dit aantal, nl. van slechts ongeveer 10 procent.

Het hoofdstuk vervolgt dan met een gedetailleerde analyse van enige gedeelten van de formule, zoals het effect van de gemiddelde snelheid op de gemiddelde tussenruimten tussen de rijdende voertuigen, op verschillende categorieën wegen.

Hoofdstuk 2: De dagkilometrage "K"

In dit hoofdstuk wordt een gedetailleerde vergelijkende analyse van 34 steden gegeven. De analyse is gebaseerd op de gepubliceerde rapporten van integrale vervoersstudies, die zijn uitgevoerd in steden met uiteenlopende cijfers wat betreft bevolking, motorisering en oppervlakte.

De analyse toont aan dat alle verplaatsings-parameters die bepaald zijn door middel van ingewikkelde en kostbare methoden, bij eerste benadering kunnen worden verklaard en gedefinieerd door eenvoudige betrekkingen tussen 2 veranderlijken, zoals: De ritproductie van personenauto's - door hun totale aantal in het gebied; de ritlengte - door de straal van het gebied; de bedrijfsauto's en hun ritten - door het motoriseringsniveau; enz.

Het hoofdstuk besluit met een methode voor te stellen, waarbij de basis-parameters van de voertuigverplaatsingen, het totaal aantal ritten en de kilometrage in een gebied, op eenvoudige en snelle wijze, en binnen de practische grenzen van nauwkeurigheid, kunnen worden gesynthetiseerd.

Hoofdstuk 3: Het wegennet

De vergelijkende analyse van de 34 steden werd eveneens voortgezet voor de wegennetten.

In dit hoofdstuk wordt aangetoond dat de gedeelten van de kilometrage afgelegd op de verschillende categorieën wegen in een stedelijk gebied in verband kunnen worden gebracht met het absolute aan-

tal personenauto's in het gebied. Drie categorieën wegen worden gedefinieerd: autosnelwegen (freeways), hoofdverkeerswegen (arterials) en ontsluitingswegen (locals).

Bovendien wordt de aandacht gevestigd op het sterke verband tussen de rijstroken en weglengte-dichtheden en de kilometrage-dichtheden, waarbij de dichtheden zijn uitgedrukt in de eenheid van grondoppervlakte.

Aldus kan de gesynthetiseerde kilometrage voor een stedelijk gebied, zoals afgeleid volgens de methode welke in het vorige hoofdstuk is uiteengezet, nu ook worden gebruikt voor het synthetiseren van de componenten van de wegennetten.

Als aanvulling wordt nog een eenvoudige methode voorgesteld voor het berekenen van de tussenruimten tussen de wegen voor netten van autosnelwegen en hoofdverkeerswegen, en wel voor diverse kilometrage-dichtheden.

Hoofdstuk 4: Verkeersmodellen

Het doel van dit hoofdstuk is aan te tonen hoe de totale kilometrage welke voor een gebied is afgeleid, door middel van eenvoudige en snelle methoden over de verschillende deelgebieden (zones) kan worden verdeeld.

Het hoofdstuk begint met een kort historisch overzicht van de conceptie van verkeersmodellen welke aanvankelijk waren ontwikkeld voor toepassing op het gebied van de sociale wetenschappen.

De nadruk wordt echter gevestigd op het feit dat in de verkeerskunde voornamelijk gebruik is gemaakt van "vectoriële" modellen, namelijk die welke zijn gebaseerd op richtingsgebonden "Herkomst- & Bestemmings"-matrices, zoals het zwaartekrachtsmodel en de afleidingen daarvan. De "scalaire" modellen anderzijds, welke zijn gebaseerd op potentiaalvelden, zijn verwaarloosd, ofschoon een paar experimenten in deze richting in het hoofdstuk worden geciteerd.

Aanbevolen wordt daarom om in de verkeerskunde meer aandacht te besteden aan "potentiaalveld"-modellen, welke in de sociale wetenschappen uitgebreid worden toegepast.

Een gedetailleerde analyse van potentiaalvelden van diverse parameters in een stedelijk gebied versus de verkeersintensiteiten doet vermoeden dat de beste overeenkomst zou kunnen worden gedefinieerd tussen de gradiënt van het potentiaalveld van de bevolking en de gradiënt van de verkeersintensiteiten.

Gesuggereerd wordt daarom om het potentiaalveld van de bevolking te gebruiken als maatstaf om de verdeling van de verkeersintensiteiten in een stedelijk gebied te schatten.

In de volgende paragraaf zal daarom worden aangetoond hoe de kilometrage van de verplaatsingen in een stedelijk gebied in verband kan worden gebracht met de intensiteiten; aldus kan de ruimtelijke verdeling hiervan in het gebied worden gedefinieerd door middel van een eenvoudige methode.

Hoofdstuk 5: Verkeer op het wegennet

In dit hoofdstuk worden wegennetten en het verkeer daarop op verschillende wijzen met elkaar in verband gebracht.

In de eerste plaats wordt het maximum aantal voertuigen dat een stadscentrum (C.B.D.) kan binnengaan, berekend. Daarna volgt een evaluatie van verscheidene methoden voor het verdelen van de kilometrage in een gebied, zoals de intensiteit-kilometrage-methode.

Van bijzonder belang is de nieuwe methode om de kilometragedichtheid in verband te brengen met de verhouding tussen wegendichtheid en snelheid. Aldus kan door het ontwikkelen van het verband op basis van een kleine steekproef in een gering aantal deelgebieden (zones) bij eerste benadering de kilometrageverdeling in het gebied worden geschat door alleen de snelheden in de diverse deelgebieden (zones) te meten. Ook wordt aangetoond dat hetzelfde verband verder kan worden ontwikkeld om de verkeersprestatie in een gebied uit te drukken in de "kinetische energie" van het verkeer, namelijk door de gemiddelde intensiteit per eenheid van lengte van het netwerk te vermenigvuldigen met de gemiddelde snelheid.

Een extra paragraaf is gewijd aan een gedetailleerde evaluatie van het verband tussen gemiddelde snelheid en intensiteit voor de di-

verse netwerken in de onderzochte steden.

De volgende paragraaf heeft weer betrekking op het "IN"-model, waarbij wordt aangetoond dat het INstant aantal voertuigen op een netwerk verband houdt met het motoriseringsniveau. Aldus kan het "IN"-aantal worden gesynthetiseerd voor elke stad, wanneer daarvan motoriseringsniveau en totaal aantal voertuigen bekend zijn.

In de volgende paragraaf van dit hoofdstuk worden twee complementaire methoden voor een volledige synthese van een wegennet en het verkeer daarop gegeven. Ook wordt aangetoond dat de verkregen schattingen voor veel praktische doeleinden binnen aanvaardbare grenzen van nauwkeurigheid liggen.

In de laatste paragraaf wordt met een rekenvoorbeeld aangetoond hoe de synthese-methoden kunnen worden gebruikt voor een snelle economische evaluatie van wegennet-alternatieven.

Hoofdstuk 6: Conclusies en aanbevelingen

De drie voornaamste conclusies en aanbevelingen uit dit laatste hoofdstuk zijn: Dat er een dringende behoefte bestaat aan het ontwikkelen van een internationale code voor standaard-definities voor de weergave van vervoersstudies; dat de methoden welke in deze dissertatie zijn ontwikkeld, verder zullen worden ontwikkeld, met een ruim gebied van mogelijke toepassingen; en dat er nog veel meer research met betrekking tot wegennetten noodzakelijk is.

Het hoofdstuk besluit met de hoop dat deze dissertatie een weg heeft helpen banen voor een beter begrip van de verkeerspatronen en het gedrag daarvan op wegennetten in stedelijke gebieden.

Postscriptum

Het postscriptum is voornamelijk gewijd aan het synthetiseren van de verkeersparameters voor nog een extra stad, t.w. Jeruzalem.

Deze recente studie heeft aangetoond dat -ondanks het feit dat de twee verenigde delen volgens vele criteria opmerkelijke ver-

schillen vertonen- de vervoerspatronen van de voertuigen in de twee delen karakteristiek zijn voor een gecombineerde en geïntegreerde voertuigpopulatie.

Aldus is opnieuw een van de basisveronderstellingen in deze dissertatie -dat voertuigen in een stedelijk gebied als een nieuwe en aparte populatie met een eigen inherent gedrag kunnen worden beschouwd- bewezen aan de hand van een extra, uniek geval.

BIJLAGEN

Zeven bijlagen besluiten de dissertatie als volgt:

1. Gedetailleerde informatie over het verband tussen snelheid en tussenruimte, voor 15 gevallen;
2. Een rekenvoorbeeld van het verband tussen snelheid, intensiteit en tussenruimte;
3. Berekening van een van de factoren in de "IN"-formule, nl. die welke de equivalentiewaarde tussen verschillende categorieën wegen uitdrukt;
4. Een gedetailleerde lijst van bronnen voor de 34 steden, die in deze dissertatie werden geanalyseerd;
5. Rekenvoorbeelden van de synthese-methode versus de gegeven data voor de onderzochte steden;
6. Gedetailleerde computeruitvoer van potentiaalvelden van vier parameters voor Tel-Aviv;
7. Bovengenoemde potentiaalvelden, in percentages, voor het tekenen van de kaarten met potentiaalvelden, welke in de dissertatie zijn opgenomen.

* * *

UNIVERSITY OF ILLINOIS-URBANA
388.4Z13S C001
SYNTHESIZING A TRANSPORTATION STUDY BY T
3 0112 007229138